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Role of science and technology in the context of international security and disarmament

Current developments in science and technology and their potential impact on international security and disarmament efforts

Report of the Secretary-General

Summary

The present report provides an overview of scientific and technological developments of relevance to weapons, means or methods of warfare and their potential impact on international security and disarmament efforts, as well as developments in relevant intergovernmental forums, pursuant to General Assembly resolution 75/38. It covers artificial intelligence and autonomous systems, digital technologies, biology and chemistry, space and aerospace technologies, electromagnetic technologies and materials technologies. The report also addresses the implications of emerging technologies for nuclear risks as well as the implications for human rights.

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Contents

I. Introduction

1. In paragraph 4 of its resolution 75/38 on the role of science and technology in the context of international security and disarmament, the General Assembly requested the Secretary-General to submit to the Assembly at its seventy-sixth session an updated report on current developments in science and technology and their potential impact on international security and disarmament efforts.

2. Science and technology contribute to human development and prosperity and are key enablers of efforts to implement the 2030 Agenda for Sustainable Development. It is important that efforts to govern new weapon technologies or weapon applications of new and emerging technologies do not hamper the economic or technological growth of any State.

3. There are, however, continuing concerns that developments in science and technology of relevance to security and disarmament are outpacing the capacity of normative and governance frameworks to understand and manage the risks. As the Secretary-General laid out in his 2018 disarmament agenda *Securing Our Common Future: An Agenda for Disarmament*, the international community must remain vigilant in understanding new and emerging weapon technologies that could imperil the security of future generations and could pose challenges to existing legal, humanitarian and ethical norms, non-proliferation, international stability, and peace and security.

4. The present report provides an overview of scientific and technological developments of relevance to weapons, means or methods of warfare and their potential impact on international security and disarmament efforts, as well as developments in relevant intergovernmental forums.

II. Recent developments in science and technology of relevance to weapons, means or methods of warfare

A. Artificial intelligence and autonomous systems

5. There is no universally agreed definition of artificial intelligence. Broadly speaking, however, artificial intelligence relates to machines with the ability to learn, solve problems, make predictions, take decisions and perform tasks that are regarded as requiring human intelligence. Contemporary artificial intelligence comprises a number of sub-disciplines and methods, such as data analysis, visual and language processing, neural networks, robotics and machine-learning. While manually coded programmes generally contain specific instructions on how to complete a task, machine-learning focuses on ways computers can learn without being explicitly programmed with instructions for generating outputs. Machine-learning is highly dependent on the quality of input and training data and on decisions made during design, development and testing. Both data and design decisions can lead to unintended vulnerabilities and biases.

6. Artificial intelligence has wide-ranging civilian applications, and the majority of research and development occurs in the civilian sphere. Recent advances in machine-learning have been fuelled by faster processors and the availability of ever-larger data sets. A number of qualities make artificial intelligence appealing, including the potential for greater efficiency and automation, as well as substantially enhanced analytical capabilities. General artificial intelligence abilities, those that can generalize and apply knowledge and skills from one domain to another, are unlikely to be available in the near future.

7. Autonomy refers to a system's ability to execute complex tasks or functions without human input or control. While there are other mediating factors, including when the human action occurs, autonomous systems either: (a) require human input at some point during the execution of the task (human-in-the-loop or semi-autonomous); (b) execute tasks independently but under the supervision of a human who can intervene (human-on-the-loop); or (c) operate independently of human involvement or supervision (human-out-of-the-loop). The elements of an autonomous system can be integrated in one machine or distributed.

Military applications and implications

8. Military applications are broad and many include non-weapon functions, such as operational support and logistics. Some States already test or field a variety of systems applying such technologies, including uncrewed aircraft capable of autonomous navigation; coordinated mobility and swarming systems; systems that sort and analyse intelligence data; defensive and offensive information and communications technology (ICT) systems; and simulation and training applications.

9. Autonomous weapon systems are generally understood to employ autonomy in critical functions during an attack, including target selection and the firing of a weapon. Systems that employ autonomy only in other functions, such as navigation, would not generally be regarded as autonomous weapons. The definition of an autonomous weapon system is the subject of continuing international deliberations (see CCW/GGE.1/2019/3). However, there are weapon systems already deployed that, once activated, are capable of selecting and engaging targets autonomously, without further human intervention, albeit in a limited range of environments. Examples include close-in weapon systems deployed on naval ships and guided munitions that select a specific target after being fired on the basis of some general or preselected criteria.

10. In commonly cited potential applications of autonomy in weapons, the autonomous functions would carry out tasks that are tedious or repetitive or require more endurance, speed, reliability or precision than a human operator. Those attributes can make such systems attractive to armed forces as well as to non-State armed groups, although non-State armed groups may accept substantially lower thresholds for accuracy and reliability. While autonomous systems can potentially perform relatively simple tasks with a high degree of accuracy and reliability, the testing, evaluation, validation and verification of such systems currently represent significant challenges. Differences between the testing environment and data collection and deployment can cause unpredictable outcomes. Equally, building the human capacity necessary for effective testing and evaluation requires significant resources and can lag behind the speed of development.

Relevant intergovernmental processes, bodies and instruments

11. At the Fifth Review Conference of the High Contracting Parties to the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects, it was decided to establish the Group of Governmental Experts on Emerging Technologies in the Area of Lethal Autonomous Weapons Systems. The Group started its work in 2017. The Group adopted consensus reports in each of its first three years of work and agreed on 11 guiding principles (see ibid.). In its 2019 report, it provided conclusions and identified aspects that might benefit from additional clarification or review under each of its agenda items. Owing to the coronavirus disease (COVID-19) pandemic, the Group could not adopt a substantive report in 2020.

B. Digital technologies

12. Digital technologies, while enormously beneficial, can also be used for malicious purposes. Threats involving such technologies are broad and range from the misuse of information and social media platforms to disseminate hate speech or fake news with an intent to incite or mislead, to large-scale attacks aimed at disrupting or taking down computer networks or systems using malicious tools and techniques. Harmful activity can be directed at different types of ICT networks and systems and can run through different layers of the Internet, including its physical infrastructure, network and routing functionalities, and applications and content. Such activity can also affect technologies that rely on several of those elements, such as cloud-based services or networked devices. A critical but not often discussed threat is potential kinetic attacks on digital infrastructure, such as the destruction of undersea cables and other physical infrastructure that enables digital connectivity. In his 2020 report entitled "Road map for digital cooperation: implementation of the recommendations of the High-level Panel on Digital Cooperation" (A/74/821), the Secretary-General outlined recommendations for action to take forward cooperative efforts in vital areas within the digital arena.

Critical infrastructure

13. As global dependence on digital technologies increases, a mounting concern is the protection of critical infrastructure from malicious attacks. Malicious cyberactivities on critical infrastructure, including power grids and water systems, have already been reported. The COVID-19 pandemic has increased the importance of protecting health-care infrastructure. Hospitals, medical research facilities and other critical institutions, including the World Health Organization, have become the target of malicious cyberactivity during this critical period. Malicious uses of digital technologies have been also reported to have impacted the life cycle of the COVID-19 vaccine, from research and development to distribution.

Increasing digital vulnerabilities

14. By 2025, it is expected that there will be more than 30 billion Internet-of- things[1] connections, almost four Internet-of-things devices per person on average, amounting to trillions of sensors connecting and interacting. The availability of increasing Internet capacity will further encourage rapid expansion of the attack surface[2] through the proliferation of connected devices that may be a challenge to secure. Furthermore, given the simplicity and the low price of many available Internet-of-things devices, security is not always an integral part of the device. This can also mean that there is no long-term security support (patching) by the manufacturer.

Dark web and digital tools: Challenges to regulation

15. The dark web, which is not accessible through traditional search engines, allows for anonymized and encrypted searches through specialized browsers. The nature of the dark web can enable criminal activity, and the COVID-19 pandemic has brought on a surge in both cybercrime and dark web utilization. Undisclosed software vulnerabilities in ICT systems have also been known to be traded on the dark web.

16. The proliferation of digital communication tools is making it challenging for law enforcement agencies to detect criminal activity and to intervene. The proliferation of social media platforms and other digital meeting spaces afford

[1] The Internet of things broadly refers to devices and equipment that are readable, recognizable, locatable, addressable and/or controllable via the Internet.

[2] The vulnerabilities that can be exploited for malicious information and communications technology (ICT) activity.

opportunities for malicious actors to communicate and coordinate and are potentially expanding beyond control.

Advances in artificial intelligence and quantum computing

17. Continued innovations in artificial intelligence and the maturation of quantum computing technology bring into focus new possibilities. Artificial intelligence, as addressed elsewhere in the present report, has specific implications for security in the use of ICTs. It is already contributing to the increasing sophistication and effectiveness of cyberattacks, such as through the enabling of better phishing attacks or the analysis of all possible attack vectors and the selection of those most likely to succeed. Quantum computing is an emerging field that may have both an enabling as well as a transformative impact in the digital space. Quantum computing may enable exponentially higher computing speeds and an ability to solve problems of higher complexity than the current generation of computers.

18. Progressive advances in artificial intelligence and quantum computing could increase the possibility of future autonomous cyberoperations involving intelligent software, and the breaking of encryption protocols, a central pillar of our current cybersecurity and privacy architecture.

Relevant intergovernmental processes, bodies and instruments

19. In 2018, the General Assembly established an open-ended working group on developments in the field of information and telecommunications in the context of international security (see resolution 73/27), open to all Member States. The same year, the Assembly also mandated the establishment of a new group of governmental experts on advancing responsible State behaviour in cyberspace (see resolution 73/266). In March 2021, the open-ended working group adopted a consensus report (A/75/816), which contains recommendations on action-oriented measures to address existing and potential ICT threats in the areas of: (a) rules, norms and principles for responsible State behaviour; (b) international law; (c) confidence-building measures; (d) capacity-building; and (e) regular institutional dialogue. The group of governmental experts adopted a consensus report on 28 May 2021. The Office for Disarmament Affairs and the United Nations Institute for Disarmament Research provided substantive support to those ongoing intergovernmental processes.

20. In 2020, the General Assembly, through its resolution 75/240, established a new open-ended working group on security of and in the use of information and communications technologies 2021–2025. The group is mandated to further develop the rules, norms and principles of responsible behaviour of States; consider initiatives of States aimed at ensuring security in the use of ICTs; establish, under the auspices of the United Nations, regular institutional dialogue with the broad participation of States; continue to study, with a view to promoting common understandings, existing and potential threats in the sphere of information security, inter alia, data security, and possible cooperative measures to prevent and counter such threats, and how international law applies to the use of ICTs by States, as well as confidence-building measures and capacity-building. The group will hold its first substantive session in December 2021.

C. Biology and chemistry

21. The norm against the hostile uses of chemistry and biology, as enshrined in international law,[3] is long-standing. However, recent uses of chemicals as weapons, combined with advances in chemistry and biology, threaten to undermine legal and normative measures.

22. Multiple technologies in the life sciences are advancing and converging to generate considerable potential benefits for society at large. However, the same technologies also raise significant safety and security issues. Trends in three broad areas are particularly facilitating advances: the growing capacity to read, write and edit DNA; the development of tools that enable the manipulation of biology at the nanoscale; and the increasing role of big data and artificial intelligence. While research and development in those fields are overwhelmingly undertaken for peaceful purposes, several ethical, legal, safety and security concerns exist. They include developments that could feed into new forms of biological weapons and ease access to or production of known biological weapons.

23. In neuroscience, a greater understanding of neurology can advance the treatment of psychiatric disorders. However, such research could potentially facilitate the development of new types of biological weapons, entailing cognitive, behavioural or neurophysiological modification. While improved understanding of immune responses can contribute to improved vaccines and therapeutics, the same knowledge could be exploited for hostile purposes in new weapons capable of more effectively overwhelming immune responses. Advances in understanding human genetics and reproductive science could play a role in treating infertility and genetically inherited diseases. However, such technology has raised ethical and safety concerns in that it could be exploited for hostile purposes. In agriculture, "gene drive" technology enables scientists to change inherited characteristics of a target species of animals or plants. Gene drives have therefore been proposed for various functions, including efforts to eradicate the malaria-carrying mosquito. That, too, raises ethical and safety concerns, as well as concern over hostile exploitation. Lastly, while research on infectious disease can improve disease response and aid the creation of new and better countermeasures, some research in that area, such as the modification of strains of avian influenza, has raised additional safety and security concerns.

24. With regard to chemical weapons, the remarkable progress made in understanding life processes at the molecular level has resulted in a greater ability to manipulate and interfere with such processes. Capabilities in those areas are expected to continue to grow. Computational tools to design molecules that can target specific cell types and highly active pharmaceutical-based chemicals that act on the central nervous system have led to concerns about the possibility of new types of toxic chemical weapon agents. There is also increased risk from more rudimentary chemical weapons. The growing availability of knowledge on improvised chemical dispersal devices combined with easy access to commercially available toxic chemicals presents new challenges for security and disarmament.

25. The crossover between the domains of biology and chemistry also requires consideration. Chemicals are increasingly being produced using biologically mediated processes, such as microbial fermentation or the use of enzymes as catalysts.

[3] Through the 1925 Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare, the 1972 Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction (Biological Weapons Convention) and the 1993 Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction (Chemical Weapons Convention).

In addition, substantial advances have been made in the chemical synthesis of molecules of biological origin. Multidisciplinary research teams continue to expand beyond biology and chemistry to incorporate ideas and approaches from other disciplines, including computing, materials science and nanotechnology. That convergence provides significant social and economic benefits, including through improved defensive countermeasures against chemical and biological warfare agents. However, such new approaches and processes, combined with developments in drug discovery and delivery, could also be exploited in the development of new toxic chemicals to be used as weapons.

Relevant intergovernmental processes, bodies and instruments

26. Both the Biological Weapons Convention and the Chemical Weapons Convention have provisions for review conferences every five years, at which relevant scientific and technological developments are reviewed.

27. Both treaties also have more regular means of reviewing relevant developments in science and technology. The Chemical Weapons Convention established a Scientific Advisory Board consisting of 25 eminent scientists, which reports to the Director General of the Organisation for the Prohibition of Chemical Weapons. In 2020, the Scientific Advisory Board convened its twenty-ninth and thirtieth sessions. In 2020, the Director General announced his intention to establish a new temporary working group on the analysis of biotoxins.

28. While several proposals for a scientific advisory body or mechanism for the Biological Weapons Convention have been made, States parties have not thus far agreed on such an approach. From 2012 to 2015, a review of developments in the field of science and technology related to the Convention was a standing agenda item. Starting in 2018, States parties have established an annual Meeting of Experts to review developments in the field of science and technology related to the Convention. The 2020 meeting was postponed owing to the COVID-19 pandemic and is now planned to take place in 2021. The importance of the discussions on the convergence between the Chemical Weapons Convention and the Biological Weapons Convention has been recognized and the discussions now take place in a biennial forum on the topic.

29. In 2020, the United Nations Institute for Disarmament Research convened its annual Innovations Dialogue, which addressed the topic of "Life Sciences, International Security and Disarmament". The event took place virtually owing to COVID-19.

30. Pursuant to Security Council resolution 1540 (2004), States are required to establish and strengthen controls to prevent the proliferation of biological and chemical weapons and their means of delivery to non-State actors.

D. Space and aerospace technologies

Missile technologies

31. Developments in emerging technologies are enabling new and expanded functions of missile systems, with implications for international peace and security and efforts to ensure the effective regulation of arms, non-proliferation and respect for humanitarian principles.

Accuracy

32. A growing number of States continue to pursue and refine various technological innovations to increase the accuracy of their ballistic missiles and artillery rockets. Such innovations have included the incorporation of modern avionics into missile systems; flight trajectory tracking, including by ground-based radar, optical sensors,

radar imaging, and navigation and positioning satellites; post-boost vehicles that enable a warhead to manoeuvre outside the atmosphere; and the increasing deployment of re-entry vehicles with aerodynamic controls, enabling those weapons to manoeuvre in the atmosphere, including in the terminal phase of flight.

33. Increases in the accuracy of ballistic missiles have various implications. Increases in the accuracy of nuclear-capable missiles can enable more States to deploy strategic systems equipped with nuclear warheads with smaller explosive yields, or with conventional warheads. Nuclear weapons with smaller or variable yields can potentially be assigned to an expanded range of roles and military missions, increasing the military utility of such weapons and affecting perceptions of "usability".

34. Increases in the accuracy of missile systems have ostensibly enhanced the military utility of ballistic missiles as tactical or battlefield weapons, as demonstrated by their proliferation and use in recent years, including by non-State actors, in the Middle East. It has also enabled the development of concepts for long-range conventional strike, including arming intercontinental ballistic missiles with conventional warheads, prompting concerns over international stability given that it remains unclear how the launch of such systems could be distinguished from a nuclear-armed system.

35. Increases in the accuracy of large-calibre artillery rockets have resulted in the development of systems that blur distinctions between artillery rockets and ballistic missiles capable of delivering a nuclear weapon. That trend poses a challenge to regimes designed to curb the proliferation of ballistic missiles capable of delivering nuclear weapons, given that it creates demand for conventionally armed ballistic missiles that may be technically capable of delivering nuclear weapons.

36. Manoeuvrable warheads can be intended to avoid anti-missile systems. That provides incentives to States to improve and develop capabilities and concepts for missile defence, which can be a source of tension or even international instability in certain contexts.

Hypersonic glide vehicles

37. Ballistic missiles typically reach hypersonic speeds[4] during their flight. Some States are developing and deploying vehicles with the ability to glide and manoeuvre at hypersonic speeds over long distances within the atmosphere. Like a manoeuvrable re-entry vehicle, a hypersonic glide vehicle would be launched from a booster rocket. A hypersonic glide vehicle would, however, spend most of its flight proceeding on a non-ballistic trajectory, sustained by aerodynamic lift. Thus, hypersonic glide vehicles could be capable of avoiding mid-course missile defences and challenging terminal defences, owing to their manoeuvrability or because they fly below the horizon for terminal defence radars at distances farther from their targets.

38. Research into hypersonic glide vehicles began decades ago. More recent military interest appears to stem from their potential to, for example, carry out conventional strikes at long ranges within a short span of time; evade strategic and tactical anti-missile systems; deploy effective strategic weapons with non-nuclear payloads; and strike moving targets at a long distance, including at sea. The first known weapon, possibly nuclear-armed, deployed on hypersonic glide vehicles entered into service in 2019, using an intercontinental-range ballistic missile as a booster. Those developments have led to concerns about new strategic arms competition and may be prompting interest in long-range conventional strike by a growing number of States.

[4] Generally understood as greater than five times the speed of sound.

Powered hypersonic vehicles

39. Most existing types of cruise missiles using traditional jet turbine engines are limited to travelling at subsonic speeds. As a means of developing systems that are more capable of evading air defence and anti-missile systems, a number of States are developing and testing cruise missiles that use new engine types, including scramjets, enabling sustained flight at hypersonic speeds. Scramjet engines are typically accelerated to supersonic speeds by a boost vehicle before they can sustain powered flight.

40. In recent years, a number of States have tested hypersonic cruise missiles powered by scramjet engines, and a variety of such weapon systems are being designed for launch by ground-, sea- and aircraft-based boosters and armed with conventional or possibly nuclear warheads. The primary advantage of such systems, compared with subsonic cruise missiles, is their enhanced ability to bypass air defences using their higher speed. Work on such systems by some States appears to have increased their desirability for other States, leading to an increase in the number of systems under development and the total funds allocated to those programmes as well as in the initiation of research into hypersonic vehicle defence concepts.

Anti-missile and terrestrial anti-satellite systems

41. There has been rapid growth in the capability and proliferation of anti-missile systems in recent decades, certain developments of which may have implications for international peace, security and stability as well as for disarmament efforts.

42. Surface-to-air systems that intercept their target within the lower atmosphere are increasingly common and have been extensively used in some armed conflicts and other situations, designed to counter shorter-range ballistic missiles and rockets in the terminal phase of flight. Generally, such systems have not raised concerns about stability, although their widespread deployment may prompt rivals to develop countermeasures, such as firing missiles in salvos or designing, developing and acquiring manoeuvrable systems designed to evade interception, including as described in the previous section.

43. The use of directed energy anti-missile systems, including lasers mounted on aircraft, has been explored, although no such system has been deployed. Proponents of the concept argue that such systems could be used for defence against missiles in the boost phase. In many situations, that would entail the forward deployment of such capabilities near launch sites, possibly leading to concerns about stability.

44. Some anti-missile systems are designed to strike missiles outside of the atmosphere in the mid-course phase of flight. Such systems can use kinetic impactors or explosives. The more capable of those systems have a de facto ability to strike satellites in low Earth orbit. Analysts consider that striking a satellite is easier than striking a ballistic missile, given that satellites travel in predictable paths that can be accurately measured far in advance and generally lack any means of evading threats. Serious concerns have been expressed about strategic anti-missile systems designed to counter strategic nuclear weapons, given their ability to strike satellites and the impact of such systems on security concepts based on mutual deterrence.

45. Terrestrial missiles have reportedly been specifically developed to strike satellites in low Earth orbit. The test launch of a direct-ascent missile capable of striking a satellite at the altitude of geostationary orbit has been reported. To reach such altitudes, a booster would likely require the capability of a medium-lift space-launch vehicle. This is particularly notable given that, up to this point, space-launch vehicles have not been considered as having utility as a weapon system and have been

regarded as distinct from ballistic missiles in terms of their technical characteristics, despite sharing a common technological base.

Relevant intergovernmental processes, bodies and instruments

46. The General Assembly established three panels of governmental experts on the issue of missiles in all its aspects between 2001 and 2008.[5] Although the issue of missiles remains on the agenda of the First Committee, there has been no resolution on the topic since 2008 (see General Assembly resolution 63/55).

47. There are two intergovernmental regimes comprised of voluntary measures related to missile technology. The Missile Technology Control Regime was established in 1987 with the aim of limiting the spread of ballistic missiles and other uncrewed delivery vehicles capable of delivering weapons of mass destruction. It has 35 members. The Hague Code of Conduct Against Ballistic Missile Proliferation, adopted in 2002, includes politically binding commitments by States to exercise maximum restraint in developing, testing and deploying ballistic missiles and to uphold transparency measures regarding policies on, and launches of, ballistic missiles and space launch vehicles. A total of 143 States subscribe to The Code.

48. The Advisory Board on Disarmament Matters considered hypersonic weapons in 2016, recommending further study on the topic. To that end, the Office for Disarmament Affairs and the United Nations Institute for Disarmament Research hosted a "track 1.5" meeting on hypersonic weapons in 2018, which was followed by the publication of a study entitled "Hypersonic weapons: a challenge and opportunity for strategic arms control".

49. It has been reported that the Russian Federation and the United States of America have discussed hypersonic glide vehicles in bilateral arms reduction talks.

50. The issue of terrestrial anti-satellite weapons has been raised in various United Nations bodies concerned with outer space security, including the Conference on Disarmament, the Disarmament Commission and the First Committee of the General Assembly.

Space-based technologies

51. While military and security interests drove early efforts to access and use outer space, the use of outer space today serves a broad range of civil, commercial, economic and military activities. Military forces are increasingly dependent on space-based technologies for fundamental tasks, such as early warning systems, navigation, surveillance, targeting and communication. Space systems, including satellites, are particularly vulnerable to various counter-space capabilities, including harmful use of ICTs, electromagnetic interference, laser dazzling, spoofing and jamming, and terrestrially launched anti-satellite weapons. A number of those capabilities can also target the terrestrial component of space systems. However, the present section focuses on recent developments in space-based technologies with possible anti-satellite applications.

On-orbit servicing and active debris removal

52. Robotic on-orbit servicing capabilities are being developed by national civilian and military entities and commercial companies. Such capabilities rely on a number of component functions, including manoeuvring, close approach, rendezvous, docking and grappling. Certain operations require some of those functions to be performed autonomously. Applications for such capabilities include satellite

[5] See A/57/229, A/61/168 and A/63/178.

refuelling, repair and transportation. Systems capable of such activity in both low Earth orbit and geostationary orbit are being actively developed and brought into operation. In February 2020, the first commercial satellite servicer successfully docked with the 17-year-old Intelsat 901 satellite.

53. The related concept of active debris removal refers to the use of a third-party spacecraft to dispose of space debris. Various State and commercial entities are developing and testing such systems through a variety of technological techniques. Most involve rendezvousing with a target, capturing it and modifying its trajectory so that it will burn up in the atmosphere. Strategies being explored include the use of small satellites equipped with robotic arms, nets, harpoons and adhesives. There have also been academic studies on the feasibility of using space-based lasers to destroy relatively small-scale space debris. No such systems have been put in regular service, although certain concepts have been tested in space.

54. While automated rendezvous and proximity operations in space have been carried out for decades, on-orbit servicing differs in the sense that it involves interactions between two space objects that were not both specifically designed to cooperate with each other. There is concern that satellites capable of performing rendezvous and proximity operations could be used for unwanted, risky, disruptive or hostile acts or that it would be impossible to interpret their purpose directly from their behaviour, particularly given their ability to approach a satellite without its cooperation and in the absence of norms for the responsible use of such systems.

Space-based lasers

55. Space-based lasers with power as low as 10 watts can potentially dazzle or temporarily blind sensors. Some experts believe 40-watt lasers can damage certain sensitive components. The first laser-based communication system was deployed in November 2016. Such means are less susceptible to conventional jamming techniques than radio communication. The further development of such systems could lead to increasing deployment of higher-powered space-based lasers. Research is also under way into the use of space-based lasers for deflecting asteroids or other objects posing a risk to Earth.

Relevant intergovernmental processes, bodies and instruments

56. Existing international law prohibits the placement of nuclear weapons or any other weapons of mass destruction in orbit or on celestial bodies or the stationing of such weapons in outer space in any other manner; the establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military manoeuvres on celestial bodies; and any nuclear weapon test explosion, or any other nuclear explosion, in outer space.

57. The prevention of an arms race in outer space has been on the agenda of the Conference on Disarmament since 1985 and has been one of the core issues on its agenda for more than two decades.

58. The Group of Governmental Experts on Transparency and Confidence-building Measures in Outer Space Activities agreed upon a consensus report in 2013 (A/68/189). In 2018, the Disarmament Commission agreed to add to its agenda for the 2018–2020 cycle the following item: “In accordance with the recommendations contained in the report of the Group of Governmental Experts on Transparency and Confidence-building Measures in Outer Space Activities (A/68/189), preparation of recommendations to promote the practical implementation of transparency and confidence-building measures in outer space activities with the goal of preventing an arms race in outer space”. In 2019, the Committee on the Peaceful Uses of Outer Space adopted the preamble and 21 guidelines for the long-term sustainability of outer

space activities. The Committee subsequently re-established the Working Group on the Long-term Sustainability of Outer Space Activities with a five-year plan, commencing in 2021, following a delay of one year owing to the COVID-19 pandemic.

59. The Group of Governmental Experts on further practical measures for the prevention of an arms race in outer space, established pursuant to General Assembly resolution 72/250, met in 2018 and 2019. It discussed a number of emerging issues, including possible measures related to rendezvous and proximity operations as well as active debris removal. The Group was ultimately unable to reach consensus on a final substantive report (see A/74/77).

60. By its resolution 75/36 on reducing space threats through norms, rules and principles of responsible behaviours, the General Assembly sought the views of Member States on various aspects of the topic and requested a substantive report by the Secretary-General (to be issued as A/76/77).

E. Electromagnetic technologies

61. A variety of weapon technologies exist or are under development that use electromagnetic energy to achieve their primary effect or as a means for propulsion. These weapons can be divided into three general categories: (a) electronic warfare capabilities, which deny, impede or destroy an adversary's ability to access the electromagnetic spectrum; (b) directed-energy weapons, which use electromagnetic energy to cause physical damage or destruction; (c) electromagnetically propelled weapons, such as rail guns or coil guns, that use electromagnetic energy to accelerate a solid projectile to a high velocity.

62. Modern military systems frequently rely on sensors, guidance systems and communications that use electromagnetic signals. Electronic warfare systems exploit that reliance through jamming, disrupting, spoofing or hacking those signals. The term also encompasses systems for countering such attacks. Electronic warfare systems can be fixed or mounted on ground vehicles, crewed and uncrewed aircraft, ships and missiles. They could hypothetically be deployed under the sea or in outer space. As such, electronic warfare systems have the potential for large-scale disruption or disabling of digital connectivity. While attempts are being made to defend certain critical infrastructure against such attacks, this remains a significant global vulnerability. The use of such systems can fall within a grey area that some States may regard as being below the threshold of the use of force or armed attack. Nonetheless, the potential use of such capabilities to target critical military infrastructure, such as early warning satellites, has raised concerns in recent years.

63. Directed-energy weapons include lasers, high-power microwaves and particle beams. Of those, terrestrial-based high-energy lasers may have the most immediate potential for destructive and disruptive applications. Laser weapons and high-power microwaves are of particular interest for air and missile defence, especially to counter uncrewed aerial vehicles, given their precision, speed and low cost per "shot". Terrestrial-based lasers have also reportedly been used by States to blind or dazzle the optical sensors of surveillance satellites. Size and weight limitations have been partially addressed by advances in solid-state laser technology. Research is ongoing regarding very small fibre lasers in arrays, free-electron lasers as directed-energy weapons, and electromagnetic pulses as anti-satellite weapons.

64. Electromagnetically propelled weapons, such as rail guns or coil guns, could have ranges up to 200 km and could be capable of launching projectiles to greater speeds than chemical propellants. Such weapons could potentially be lighter and cheaper than missiles with comparable ranges. At short ranges, their projectiles could

be capable of destroying targets with kinetic energy alone. While advances have aided the development of prototypes, technical barriers remain, including the requirement for a large power supply and sufficiently robust components. Such weapons are primarily considered for anti-access/area denial and naval defence roles. The test-firing of railguns has taken place, and such weapons are expected to be deployed before the end of the present decade.

Relevant intergovernmental processes, bodies and instruments

65. Electronic warfare capabilities and directed energy weapons were discussed by the Group of Governmental Experts on further practical measures for the prevention of an arms race in outer space (see A/74/77). Current views by Member States can be found in the report of the Secretary-General pursuant to General Assembly resolution 75/36 on reducing space threats through norms, rules and principles of responsible behaviours (to be issued as A/76/77).

F. Materials technologies

66. The present section addresses developments in both manufacturing techniques and new types of materials.

67. Additive manufacturing has brought novel changes to production. It has also lowered the technological threshold for State and non-State actors to build complex components, including production equipment for fissile materials and chemical or biological weapons. While technical limitations remain, the potential for the use of additive manufacturing for proliferation purposes increases every year. That is especially true when combined with enabling technologies such as artificial intelligence, which can, inter alia, reduce the risk of error, facilitate automated production and, through simulated prototyping, make feasible the printing of previously "unprintable" components.

68. Additive manufacturing is already used by some States to produce nuclear-weapon-related items, such as high-explosive lenses in nuclear warheads. Furthermore, the additive manufacturing supply chain is becoming increasingly difficult for governments to monitor. Additive manufacturing decentralizes production, potentially obviating export controls. It has also increased the significance of intangible transfers of technology and software-based designs in the context of arms control.

69. Developments in nanotechnology have made it easier to produce and transport chemical and biological agents, potentially hindering non-proliferation efforts. Nanotechnology can also enhance the means of delivery for lethal biological and chemical agents by enabling new and improved processes of encapsulation and aerosolization. When coupled with synthetic biology and chemistry, the technology could also aid in the development of novel agents with enhanced lethality and resilience.

70. Militaries continue to pursue materials that enhance the quality of personal protective equipment for soldiers as well as materials that can reduce different types of signatures (for example, radar cross section, electromagnetic or heat) to increase stealth. Militaries are also exploring new materials that have higher energy per unit of mass to produce more effective explosives for use in conventional weapons and for improved propulsion for land, sea, air and space systems.

71. Trends in small arms and light weapons manufacture and design have continued to raise concerns regarding the durability of weapons marking and, by extension, the ability of States to keep accurate records and undertake effective tracing. Modular

weapons are composed of multiple components that can be reconfigured. Such modularity presents particular challenges to the requirement in the International Tracing Instrument to Enable States to Identify and Trace, in a Timely and Reliable Manner, Illicit Small Arms and Light Weapons that a unique marking be included on an essential or structural component of a weapon. In addition, the use of polymer plastics in weapons manufacture has raised concerns, given that markings on such material are more vulnerable to erasure and alteration than on more traditional materials such as steel.

Relevant intergovernmental processes, bodies and instruments

72. The Security Council, through its resolution 2325 (2016), expressed its commitment to consider the use by non-State actors of rapid advances in science, technology and international commerce for proliferation purposes in the context of the implementation of resolution 1540 (2004). The Council also encouraged States to control access to intangible transfers of technology and information that could be used for weapons of mass destruction and their means of delivery.

73. In the context of the Programme of Action to Prevent, Combat and Eradicate the Illicit Trade in Small Arms and Light Weapons in All Its Aspects, Member States continued to exchange on recent developments in weapons technology, design and manufacturing and their implications for the International Tracing Instrument. Special attention continues to be paid to the use of polymer materials and modular design given their potential to undermine the long-term viability of markings and tracing. In advance of the seventh Biennial Meeting of States to review the implementation of the Programme of Action on Small Arms and International Tracing Instrument, in July 2021, States informally exchanged views on related technological developments. In parallel, the General Assembly continued to recognize the opportunities and challenges associated with those developments, including polymer and modular weapons, and called for them to be addressed in a timely manner (see resolution 75/241).

III. Implications of emerging technologies for nuclear risks

74. The international system is becoming more multipolar, with a deteriorating international security environment, nuclear weapons assuming greater roles in strategic doctrines and unprecedented expenditures to upgrade arsenals. Military applications of emerging technologies may increase the chances of conventional armed conflict between nuclear-armed States, creating more situations in which nuclear escalation becomes a possibility. The risk of the use of nuclear weapons has now reached heights not seen since the Cold War. The most immediate danger is the creation of more numerous, shorter and interlinked pathways to misperception, miscalculation and escalation.

75. Many scientific and technological advances are being used to make nuclear weapons and their delivery systems more accurate, faster and stealthier and, in the view of some, more usable.

76. Technologies with the potential to increase the risk of nuclear weapons include those related to missile defences, advanced long-range missiles (including hypersonic glide vehicles and hypersonic cruise missiles), anti-satellite systems, ICTs and applications of artificial intelligence.

77. Such technologies are introducing elements of unpredictability at a time of international tension, when concepts of nuclear deterrence are being re-evaluated, there is an absence of guardrails for new capabilities with strategic consequences and

arms control frameworks are eroding. They are also being introduced amidst concerns about the lack of common understanding among nuclear-armed States on crisis and escalation management, especially with respect to attacks on critical infrastructure such as satellites.

78. In the nearer term, developments could undermine international stability and impact security concepts based on mutual deterrence. For example, offensive cybercapabilities could interfere with the ability of early warning systems to provide timely accurate information. Precision-strike conventional weapons could target infrastructure critical to the command and control of nuclear weapons. Such developments could create destabilizing perceptions about the necessity of using nuclear weapons first, furthering the likelihood of misperception leading to rapid and uncontrolled escalation.

79. Concerns about the impact of emerging technologies are driving risk-generating behaviour such as arms racing. Examples include ongoing efforts to develop and field hypersonic weapons, despite concerns that such weapons add no viable advantages,[6] or expanding nuclear doctrines that potentially increase the scenarios in which nuclear weapons would be used in response to non-nuclear capabilities or to attacks on critical infrastructure.

80. The nexus between nuclear weapons and emerging technologies potentially introduces dangerous ambiguities that could drive escalation and miscalculation. Strategic ambiguity results from a wider array of non-nuclear strategic attacks, for example cyberattacks, and the prospects for a nuclear response. Operational ambiguity is associated with "strategic conventional weapons" and systems capable of carrying nuclear or conventional payloads. There is also ambiguity of intent regarding possible attacks against multi-purpose support systems such as communications, earth observation or positioning, navigation and timing. Attacks on such infrastructure in the context of a conventional crisis could be misinterpreted. Such "entangled" interaction can drive escalation through miscalculation.

81. Several emerging technologies have exposed potential new vulnerabilities for nuclear weapons and command, control and communications. The use of offensive cybercapabilities to attack or interfere with nuclear command, control and communications is perhaps the most immediate concern, especially given the attribution problems involved. Similarly, the use of lasers to "dazzle" early warning satellites or machine-learning to "spoof" nuclear command, control and communications could increase the possibilities of miscalculation and create escalatory pressures, including through the involvement of malicious third parties.

82. Some emerging technologies could also further lower the barrier to the use of nuclear weapons by targeting previously shielded capabilities such as mobile launchers and nuclear-capable submarines. The use of, inter alia, autonomous uncrewed vehicles, machine-learning and enhanced remote-sensing capabilities could facilitate the tracking of such capabilities, creating a growing reliance on maintaining nuclear weapon systems on alert with a detrimental impact on escalation control or possibly leading to perceived needs to increase the number of delivery vehicles to avoid detection.

83. Emerging technologies have the potential to truncate decision-making processes regarding the use of nuclear weapons. "Hypersonic weapons" could reduce the already limited time available to decision-makers. Non-kinetic interference with

[6] John Borrie, Amy Dowler and Pavel Podvig, "Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control" (New York, United Nations Office for Disarmament Affairs and United Nations Institute for Disarmament Research, 2019). Available at un.org/disarmament/wp-content/uploads/2019/02/hypersonic-weapons-study.pdf.

nuclear command, control and communications undermines the ability to trust and verify information, which is potentially further exacerbated by issues such as the "black box" nature of some artificial intelligence. Such risks are increased considerably in the nuclear context given the catastrophic consequences of use and are exacerbated by doctrinal positions such as "launch on warning".

IV. Implications for human rights

84. The Human Rights Council and its special procedures, the human rights treaty bodies and the United Nations High Commissioner for Human Rights have addressed the implications under international human rights law and international humanitarian law related to various emerging weapon technologies, including armed drones, lethal autonomous weapon systems, less lethal weapons and ICTs.

85. Particular attention has been given to weapon systems that make it easier to target individuals in two scenarios, namely, outside of active battlefields or in territories where an armed conflict does not exist and where only international human rights law applies, not international humanitarian law. Much of the focus has been on armed drones, but the implications of lethal autonomous weapon systems have also been addressed.

86. Arbitrary killings are prohibited under international human rights law (A/68/389, para. 60). The use of potentially lethal force for law enforcement purposes is an extreme measure, which should be resorted to only when strictly necessary in order to protect life or prevent serious injury from an imminent threat. The intentional taking of life by any means is permissible only if it is strictly necessary in order to protect life from an imminent threat. When using lethal force with, for example, a drone outside of a situation of armed conflict, the killing of anyone other than the target (who must present an imminent threat to life or serious injury to be targeted), such as any others in the vicinity, would be an arbitrary deprivation of life (A/HRC/14/24/Add.6, para. 86).

87. Special rapporteurs have expressed concern that developments in technology are creating incentives for States to expand or distort their interpretation of international law, especially *jus ad bellum*, given that newer weapon systems provide a capacity to carry out targeted killings at anytime and anywhere in the world, against both State (see A/HRC/44/38) and non-State actors.

88. New weapon technologies have posed various challenges for accountability when there are credible allegations of right-to-life violations. Armed drone operations are carried out by institutions that are not able to publicly disclose information on the criteria used to select targets or the precautions that have been incorporated into such criteria (A/68/382, para. 98). Such institutions may lack any official record of the persons killed (ibid., para. 99). That lack of transparency makes it difficult to assess claims of unlawful conduct, creates an accountability vacuum and affects the ability of victims to seek redress (A/68/389, para. 41). In some cases, courts have also been unwilling to provide oversight over the extraterritorial use of armed drones in targeted killings (see A/HRC/44/38). While such concerns have been most articulated in relation to armed drones, other emerging capabilities, such as lethal autonomous weapon systems and ICTs, which can threaten critical infrastructure, may be attractive to such institutions, including those involved in so-called hybrid warfare.

89. In addition to risks to the right to life, the possible use of novel targeting criteria has raised questions about discrimination (A/68/389, para. 74), including on the basis of sex and gender, race or ethnic origin, and age, and whether States apply the same standards for citizens and non-citizens (A/68/382, para. 39).

90. It has also been noted that the incorporation of new technologies into weapon systems can assist efforts to uphold human rights, including by recording information on possible violations and in aiding investigations into right-to-life violations. Certain technologies, such as sensors, cameras and ICTs, when used on platforms such as drones, can facilitate more accurate targeting as well as the conduct of post-operation assessments (A/71/372, para. 84). Body-worn cameras, which can be used in both armed conflict and in law enforcement settings, can also serve as a source of evidence for accountability (ibid., para. 85).

V. Conclusions and recommendations

91. **Many of the developments addressed in the present report are the subject of recent or active multilateral deliberations within the framework of the United Nations or elsewhere. United Nations entities will continue to support and facilitate existing and potential new processes to address emerging challenges before they can pose a danger to peace and security, human rights, humanitarian norms and principles, or other purposes and objectives of the Organization.**

92. **Various actions relating to emerging technology set out in the Secretary-General's disarmament agenda *Securing Our Common Future: An Agenda for Disarmament* recognize the importance of multi-stakeholder engagement and commit to facilitating such engagement in various contexts. Member States have recognized the growing interest in engaging with multiple stakeholders, including industry and other private sector actors, in intergovernmental processes. It is recommended that United Nations bodies and entities continue to encourage multi-stakeholder and geographically equitable engagement, including by industry and other private sector actors, through formal and informal platforms.**

93. **Member States are encouraged to continue to seek ways of integrating reviews of developments in science and technology in their work, including through processes to review the operation of disarmament treaties and within all relevant United Nations disarmament bodies.**

94. **Developments in one particular area of science and technology may have relevance to the work of many different disarmament processes and bodies. It is therefore recommended that processes to review the operation of disarmament treaties and all relevant United Nations disarmament bodies devote specific time to keeping up to date with all relevant work undertaken in other processes and bodies that address issues connected with developments in science and technology.**

95. **It is recommended that reports containing updates to the information in the present report continue to be submitted on an annual basis, as a contribution to maintaining awareness of developments in science and technology and their potential impact on international security and disarmament efforts.**