ENVISIONING SUSTAINABLE SECURITY

The evolving story of Science and Technology in the context of disarmament

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CONTENTS

SUMMARY

- × The renewed interest of stakeholders in multilateral weapons control in the security and disarmament implications of developments in science and technology (S&T) provides an opportunity for critical reflection on and political action aimed at realizing the vision for sustainable security outlined by the UN Secretary-General in his Agenda for Disarmament.

- × To make substantive progress, greater attention must be paid to the evolving narrative, underpinning beliefs and assumptions regarding S&T in the context of disarmament. The dominant narrative about S&T currently developing in that context suffers from some weaknesses:

  - It unquestioningly reproduces the belief in the progressive and beneficent character of technological change and is technologically deterministic.
  - It masks diverse and competing understandings of the role played by new weapons and military applications of developments in S&T in attaining security and disarmament objectives.
  - It fails to engage earnestly with the drivers of the accelerating pace of S&T developments relevant to disarmament and understates the political importance of the ethical questioning of weapons development.
  - It portrays the process of innovation as an inescapable, ungovernable force, disempowering stakeholders in weapons control and limiting the scope for meaningful political action in favour of disarmament.
  - It risks distracting from addressing the underlying causes of stagnation in disarmament, perpetuating structural problems and entrenching escalating scientific-technological rationales for violence.

- × In the past, UN Member States viewed the ‘the qualitative improvement of armaments’ as a threat to peace and disarmament. This paper encourages stakeholders in multilateral weapons control to reconnect with this position and envision a technological future that accords with the ideals articulated in Agenda 2030, the Universal Declaration of Human Rights and the Secretary-General’s Agenda for Disarmament. It invites them to:

  - critique technology, question proposed visions of future war and future technologies’ role in organized violence and deliberate what common goods innovation in S&T should realize;
  - deliberate not only the potential uses and abuses of emerging weapons technologies, but also whether they should be introduced in the first place;
  - recognize that the promotion of responsible innovation is no substitute for political action, laws and policies and acknowledge that what is ethical remains open to ongoing debate;
  - promote processes and institutions conducive to iterative, adaptive and sustained political engagement with S&T developments and involve diverse knowledgeable people in the deliberations.

INTRODUCTION

The continuous process of development in science and technology (S&T) has implications for the emergence of new practices and technologies of armed violence, including new weapons. Emerging weapons technologies have implications for human wellbeing, peace, security and environmental protection, and provoke questions regarding the adequacy of existing legal frameworks and institutional arrangements for weapons control. As such, they are of considerable significance to the international community.

Over recent years, the security and disarmament implications of developments in S&T have attracted renewed attention in multilateral disarmament and arms control circles. The UN General Assembly has underlined 'the keen interest of the international community to keep abreast of the latest developments in science and technology of relevance to international security and disarmament and to channel scientific and technological developments for beneficial purposes'.[1] It also mandated the UN Secretary-General to report on current developments in S&T and their potential impact on international security and disarmament efforts. That report was published in July 2018[2] and key aspects of it are discussed below.

The Secretary-General's report and other recent UN documents on S&T, as well as statements and submissions by UN Member States, reflect a widely shared framing of innovation in S&T as being potentially both beneficial and detrimental to disarmament and security. Such texts also reflect broad agreement on a number of concerns about current developments in S&T of relevance to disarmament, including anxiety that they risk 'outpacing, and in some cases … sidelining, norm development'.[3] However, multilateral efforts aimed at addressing these concerns have, in practice, met with significant conceptual and political challenges. Beyond calls for the international community to 'remain vigilant in understanding new and emerging weapon technologies that could imperil the security of future generations',[4] it remains unclear, as yet, how implications of S&T developments should be assessed, threats averted and benefits realized through disarmament and wider weapons control efforts.

This paper argues that if substantive progress is to be made, greater attention needs to be paid to the evolving narrative and underpinning beliefs and assumptions regarding S&T in the context of disarmament. Within the framework of its project on 'science, technology and weaponization', aimed at fostering a better understanding of S&T developments relevant to the international control of conventional weapons, Article 36 has produced issue briefs highlighting concerns that may be raised in relation to acoustic weapons, directed energy weapons, hypersonic weapons, nanoweapons and swarms.[5] Building on these briefs and on preliminary remarks published in November 2017, this paper aims to promote critical reflection on the representation of S&T developments in the context of disarmament and the implications of that representation for multilateral weapons control.

Based on an analysis of selected recent texts on S&T in the context of international security and disarmament, this paper invites stakeholders in multilateral weapons control – representatives of states, UN agencies, as well as civil society actors like Article 36, and others – to take a closer look at how they make sense of S&T developments in the context of disarmament and related governance initiatives. Specifically, questions are raised about what is or is not identified as problematic in relation to S&T developments and what space is created for political action. The paper encourages stakeholders to envision a technological future that accords with the ideals articulated in Agenda 2030, the Universal Declaration of Human Rights and the Secretary-General's Agenda for Disarmament. The goal is to stimulate collective exploration of ways and means to make that future a reality through shared practice.

WHAT ROLE FOR S&T IN THE CONTEXT OF DISARMAMENT?

'IT IS THE BUSINESS OF THE FUTURE TO BE DANGEROUS; AND IT IS AMONG THE MERITS OF SCIENCE THAT IT EQUIPS THE FUTURE FOR ITS DUTIES.'[6]

In a resolution spearheaded by India and adopted without a vote in 2017, UN Member States underlined their keen interest 'to keep abreast of the latest developments in science and technology of relevance to international security and disarmament and to channel scientific and technological developments for beneficial purposes'.[7] Referencing ongoing discussions on developments in S&T in specialized UN agencies and disarmament fora, such as the Biological Weapons Convention, they expressed the view that 'the accelerating pace of technological change necessitates a system-wide assessment' of the potential impact of S&T developments on international security and disarmament.[8] The member states also requested that the UN Secretary-General report on current developments in S&T and their potential impact on international security and disarmament efforts, a report published in 2018.[9]

The Secretary-General's 2018 report heralds S&T as, throughout history, 'overwhelmingly ... forces for good in society'.[10] At the same time, it highlights that '[n]ew weapon technologies pose possible challenges to existing legal, humanitarian and ethical norms; non-proliferation; international stability; and peace and security', and raises concern that 'developments in science and technology of relevance to security and disarmament are outpacing, and in some cases risk sidelining, norm development'.[11]

The report provides an overview of S&T developments in relation to 'the means and methods of warfare' with a focus on 'applications that could feasibly be fielded within the next five years'. It covers the areas of artificial intelligence and autonomous systems, biology and chemistry, advanced missile and missile-defence technologies, space-based technologies, electromagnetic technologies and materials technologies. It also identifies a variety of more general trends with 'potential military applications and associated consequences for the waging of armed conflicts, and possibly peace and security more broadly'. These include a return to arms-race dynamics in the strategic sphere, growing interdependence between the civilian and military realms, an accelerated pace of technological development and the challenge of ensuring that normative efforts keep pace with them.

The account of S&T presented in the report appears to be shared by most member states, at least on the face of it. A follow-on resolution adopted without a vote in 2018 mandates the Secretary-General to submit an updated report that includes views of additional UN Member States.[12] This creates an opportunity for sustained engagement with the theme of S&T developments in the context of international security and disarmament. In light of this, stakeholders in the debate should pay close attention to the type of story about S&T that is being spun in the context of disarmament, not only because narratives are revealing of prevailing beliefs and attitudes, but also because they shape future policy-making by opening up or foreclosing space for political action.

The Secretary-General's 2018 report and UN Member States' responses to it provide interesting insights into this evolving narrative. Comparing these texts to previous articulations of S&T issues in the UN disarmament context, as well as texts on S&T situated in other policy spaces within the UN system highlights different ways of framing issues of S&T, of identifying challenges and devising policy responses.[13] It also indicates possible blind spots and limitations of the narrative now developing in the context of disarmament.[14]

CHALLENGING S&T IN THE CONTEXT OF DISARMAMENT

‘[T]HERE IS ABSOLUTELY NO INEVITABILITY AS LONG AS THERE IS A WILLINGNESS TO CONTEMPLATE WHAT IS HAPPENING’.[15]

The Secretary-General’s normative assumption that S&T are overwhelmingly forces for good in society[16] is also reflected in his Agenda for Disarmament, launched in May 2018, which credits technological progress with having ‘increased global wealth, trade and prosperity, improving living conditions in many parts of the world’.[17] The belief in the progressive and beneficent character of technological change echoes the Secretary-General’s Strategy on New Technologies[18] and initiatives in other policy spaces within the UN, such as Science, Technology and Innovation (STI) roadmaps to support the implementation of the Sustainable Development Goals (SDGs)[19] and the International Telecommunication Union’s AI for Good conference series.[20]

In contrast to these initiatives, however, the central focus in the context of international security and disarmament is on ‘possible security implications’[21] of S&T developments. Such implications take the form of ‘challenges’, ‘unclear or potential dangerous applications’ or ‘foreseeable risks’, as well as ‘beneficial applications’ and ‘application for peaceful purposes’.[22] The Secretary-General’s report and related texts tend to present S&T developments themselves as value-free and politically neutral, underlining that ‘scientific and technological developments can have both civilian and military applications’ and stressing the risk of ‘misuse’.

Accordingly, recent UN General Assembly resolutions call for S&T developments to be ‘channel[led] ... for beneficial purposes’, for the exchange of technologies ‘for peaceful uses’ to be promoted and for progress in S&T ‘for civilian applications’ to be maintained and encouraged.[23] There is no equivalent call for the promotion of ‘military applications’ of S&T, which suggests that such research and development is not viewed with quite the same enthusiasm. This does not mean, however, that the development of new weapons is identified as a problem. The texts in question do not explicitly discourage the promotion of military applications of advances in S&T. Nor do they address how ‘channeling’ of S&T for beneficial purposes is to be achieved in a situation characterized as one of 'growing interdependence between the civilian and military realms'. The Secretary-General has even stated that '[t]he accelerating development of new weapon technologies is not bad per se.' [24]

What counts as a 'beneficial purpose' or a 'beneficial application' is, of course, open to different interpretations, including:

- Applications that directly support practices of disarmament, non-proliferation or arms control, notably in terms of detection (e.g. enhanced early-warning and investigative capabilities), verification, response to weapons use (e.g. treatment of disease) and collaborative research in furtherance of such innovations are commonly assigned to the category of beneficial applications.[25]

- In the military domain, in contrast, benefits from innovation are primarily, if often tacitly, equated with greater military effectiveness in the sense of tactical or operational combat efficiency[26] (and, at times, with cost-cutting[27]). Military applications of S&T that create benefits in this sense can stand in tension with international security and disarmament objectives.

- To complicate matters further, states not infrequently laud new weapons and military applications for their security benefits in terms of, e.g., support to human decision-making in the use of force and allowing 'more precise and efficient deployment of force with a view to avoiding or minimizing incidental harm to civilians and civilian objects'.[28] Claims that new weapons result in reduced civilian harm or enhanced protection of other common goods hold the promise that military applications of S&T are beneficial in terms of human and international (collective) security as well as 'humanitarian disarmament'.[29] From this perspective, why should the application of S&T for military purposes and new weapons not be encouraged?

Whether military applications of S&T developments and weapons development is seen as a problem also depends on the weapons control context. The contribution of S&T to the 'refinement' of weapons is considered a challenge to the control of biological and chemical weapons – applications comprehensively prohibited and widely held to be beyond the pale. 'Modernization' is also a key point of contention in policy debates about nuclear weapons whose legitimacy is fiercely contested.[30] But ongoing weapons development is not viewed with equal skepticism when weapons control is framed in terms of 'destabilizing accumulation', 'transparency of military expenditures', 'unregulated flow', 'proliferation' or 'misuse' of conventional weapons.

Finally, attitudes towards weapons development vary among states. In relation to emerging weapons technologies, Nepal, for example, has stated that the 'weaponization' of new technology, such as drones and 3D printers, must be prevented because it poses a 'serious threat to humanity'.[31] But Switzerland's position probably better reflects the dominant view at present: whilst cautioning against the emergence of 'attractive new types of weapons' which could 'endanger ... existing prohibitions or restrictions', Switzerland stresses that responses should not 'hamper ... legitimate military development and use'.[32]

The rewards of advances in S&T are not equally shared among states (and members of societies). This has long been recognized within the UN[33] and may account for different attitudes towards weapons development. Yet, aside from recalling the 'rights of States ... regarding the development, production, transfer and use of technologies for peaceful purpose'[34] (respectively, the 'need to continue the exchange of technologies for peaceful uses'[35]), recent resolutions on S&T in the context of disarmament do not address the implications of these structural inequalities for international security, peace and disarmament.

The refusal to characterize the application of advances in S&T for the development of new weapons as straightforwardly problematic has to do with the entanglement of such developments with a wider S&T progress narrative. In the context of international security and disarmament, recent texts addressing new technologies tend to invoke improvements in 'our daily lives' in areas such as healthcare, communications or industrial production, to convey the beneficial possibilities on offer.[36] In such accounts of S&T, technologies of violence are entwined with technologies of social progress. Potentially detrimental implications for international security and disarmament are juxtaposed with a much wider array of potential societal benefits. This representation has a built-in bias in favour of the continued pursuit of S&T developments construed widely, compared to potential (and actual) risks narrowly conceived.[37] It makes questioning the value of S&T development difficult and facilitates the portrayal of efforts to address security or disarmament concerns as imperiling social progress. As we are dealing with technologies implicated in organized violence where some harmful consequences are clearly intended, this should give us pause.[38]

Notably, past UN accounts reflect a different attitude towards weapons development and military applications of scientific advances. In the 1978 outcome document of the First Special Session of the General Assembly on Disarmament (SSOD-I), UN Member States recognized that 'the competition for qualitative refinement of weapons of all kinds, to which scientific resources and technological advances are diverted, pose incalculable threats to peace'.[39] They acknowledged that efforts aimed at 'the limitation and cessation of the qualitative improvement of armaments, especially weapons of mass destruction and the development of new means of warfare' are needed to halt the arms race and promote disarmament.[40] A decade later, in 1988, a UN General Assembly resolution highlighted 'concern [about] the existing potential in technological advances for application to military purposes' and recognized that 'such developments will have a negative impact on the security environment while causing a major setback to disarmament efforts'.[41] At that time, UN Member States stressed 'the importance of … ensuring that scientific and technological developments are not exploited for military purposes but harnessed for the common benefit of mankind'.[42] A 1990 report by the UN Secretary-General, published in a radically changed security environment, still noted 'overriding anxiety' that 'modern technological advances may be hindering rather than helping the pursuit of international security', specifically, through the 'qualitative modernization' of nuclear and conventional weapons bringing 'dramatic increases in their range, accuracy and lethality', as well as the development of novel weapons.[43]

Varying attitudes towards military applications of S&T developments speak to a key question in any debate on S&T: 'which forms of innovation, by virtue of their character, products or intended use, should be off limits?'[44] In the context of international security and disarmament, this question is bound up with differing and at times competing visions of security that progress in S&T is meant to bring about, shifts in states' understanding of the role of S&T in the practices of organized violence, different norms and values embedded in and expressed through technologies, as well as changes in the processes of innovation and evolving configurations among science, technology, society, the market, the state and the international order.[45]

Some of these shifts are apparent in the UN Secretary-General's report published in 1994, entitled 'Scientific and Technological Developments and their Impact on International Security'.[46] It describes technological change as being driven mainly by an economic agenda, with companies and government agencies being identified as the 'prime players in the defence industry'.[47] Arguing that national security is 'becoming as dependent upon economic power as it had been on military strength', the report considered that the stakes are high for all states 'to master or acquire technologies that will give them a competitive edge'.[48] The report raised concern that this market orientation of technological development creates 'major obstacles to developing new technologies for national security'[49] and that national economies, therefore, have to face the 'crucial task' of 'integrat[ing] their defence and commercial industrial sectors'.[50] In spite of its title, the 1994 report conceived of security exclusively in terms of a national, militaristic and market-driven quest for a 'competitive edge' and did not address the implications of such an approach for international (collective) security, let alone disarmament or peace.

Today, a number of structurally empowered states still see technological dominance as a key source of national security. This is, for example, a central theme in the United States' 2018 National Security Strategy (as well as in the strategies of previous administrations), in which the US Government commits to maintain and renew its 'competitive advantage' by 'prioritiz[ing] emerging technologies critical to economic growth and security',[51] and identifies other states' access to such technologies as a threat to the US.[52] At the inter-state level, such a zero-sum outlook on international relations can be expected to sustain and even accelerate weapons development and applications of S&T for military purposes due to offence-defence dynamics and security dilemmas,[53] as well as through uncritical emulation by structurally less-empowered states.[54]

Not coincidently, recent years have seen a return to arms-race dynamics and growing resistance to multilateral, cooperative approaches to addressing international security and disarmament challenges. Whereas, to many states, it may be increasingly apparent that the route to national security is a more global approach to the management of technology, state-centric conceptions of security are, arguably, still at the centre of current approaches to global security.[55] This bears the risk that assessments of S&T developments at the multilateral level 'uncritically reproduce, rather than challenge, insecurities which are generated by state-level competition dynamics'.[56]

The narrative about S&T under development in the context of disarmament pays little attention to how and why states and other actors choose to pursue military applications of S&T innovations and create new weapons, or to how these conditions might be changed. It should be clear, however, that a national security perspective relying on technological dominance will privilege different policy responses compared to a disarmament-oriented one. Drawing on a vision of future war or a scenario of a particular future weapon, national defence rationales point to the need to redouble and speed up weapons developments. For example, developments towards increasingly autonomous weapons systems and swarms of (weaponized) autonomous systems appear to drive each other. Both are justified by reference to the increasing speed of warfare, whilst driving that acceleration.[57]

THERE IS A REAL RISK THAT ESCALATING SCIENTIFIC-TECHNOLOGICAL RATIONALES FOR VIOLENCE WILL BE PERPETUATED AND EVEN AMPLIFIED, RATHER THAN CHALLENGED BY MULTILATERAL WORK ON S&T IN THE CONTEXT OF DISARMAMENT.

A disarmament approach lends itself better to problematizing not only particular emerging weapons technologies, but the underpinning logic of weapons development and its implications for collective and human security. It allows ethical questions about the development of new technologies of violence to be moved back into the centre of the debate and opens up space for multilateral, political action.[58] Without this, there is a real risk that escalating scientific-technological rationales for violence will be perpetuated and even amplified, rather than challenged by multilateral work on S&T in the context of disarmament.[59]

With UN Member States calling for a coherent and comprehensive approach to S&T and the Secretary-General envisioning S&T developments to advance international security and disarmament in a manner that promotes sustainable development and accords with human rights,[60] urgent questions arise for stakeholders in weapons control regarding the meaning given to S&T, the framing of the problems to be addressed and the articulation of a vision for the future. If the 'disarmament community' is to unite around a shared perception of the future that should be realized (a sociotechnical imaginary), it is important to question our own and other stakeholders' assumptions, beliefs and understandings of the 'social order attainable through, and supportive of, advances in science and technology'.[61] As anticipations of the future shape our actions today, a better understanding of how the future operates in the S&T debate in the context of disarmament can help us expand what we can see and might do.[62] Some of these questions could usefully be addressed by member states in their submissions to the UN Secretary-General's 2019 report on S&T. Others indicate avenues for further research.

QUESTIONS FOR STAKEHOLDERS

- When S&T are said to bring about the progress of humanity, what does this mean for new weapons and military technologies?
- What goals, interests and values are being served by new weapons and military applications of S&T? Whose goals, interests and values are these? Are they universally shared? How do things look through a gender-lens and from different vantage points around the globe?
- How does the evolving narrative about S&T in the context of disarmament differ from S&T narratives in other policy spaces within the UN system (e.g. sustainable development)? How is technology understood in relation to the social and the political? How are military applications of S&T viewed? [63] How can a more critically reflexive practice be fostered in the context of disarmament?
- What conception of the public good should multilateral work on S&T in the context of disarmament serve? What are the benefits that advances in S&T should produce for disarmament?
- On what grounds should a development in S&T be deemed a challenge or threat to international security or disarmament? Is there a common understanding about this? How can space be created for the articulation of different visions and deliberation be promoted?
- How do visions of the future operate in the debate on S&T in the context of disarmament? Is there a shared technological vision to which stakeholders in weapons control subscribe? Do these visions accord with ideals articulated in Agenda 2030 and the Universal Declaration of Human Rights? If not, how can meaningful change be induced?

THE 'PACING PROBLEM' IN THE CONTEXT OF DISARMAMENT

'[I]T IS NEVER CLEAR A PRIORI AND INDEPENDENT OF CONTEXT WHETHER AN ISSUE SHOULD BE TREATED AS TECHNICAL OR SOCIAL.'[64]

A central theme in recent texts on S&T in the context of international security and disarmament concerns the so-called 'pacing problem' – a common trope of S&T and society literature.[65] It can be described as the 'widening speed differential between the development and dissemination of new technologies and the time needed for social deliberation on whether and how they should find a place in established ethical and legal orders, and in our wider social and physical environments'.[66] In the disarmament context, the concern is characterized varyingly as 'the accelerating pace of technological change',[67] respectively, that it enables, 'at an accelerating pace, the design and acquisition of new weapon technologies',[68] and that 'developments in science and technology of relevance to security and disarmament' might 'outpace' or 'sidelin[e] norm development'.[69] Concern about this appears to be widely shared, with UN Member States identifying it as a cause for insecurity and a rationale for policy action. Jordan, for example, argues that '[t]he remarkably rapid pace of progress in technology makes it vulnerable to risks and challenges'.[70] Switzerland cites 'the breathtaking pace of innovation and development' as the reason for its repeated calls to consider new developments in S&T at the multilateral level.[71] And for Japan, 'the rapid pace of change' makes it 'essential and useful to have input from related stakeholders, particularly from the private sector'.[72]

Depending on how this story about speed is told, different responses move to the fore. In its most common representation, the 'race' in the context of disarmament lends itself to a normative rather than a technological solution.[73] 'Pacing' is seen as a key challenge for regulatory oversight, encapsulated in the question: 'how can regulatory oversight arrangements keep pace with rapid scientific and technological innovation?'[74] This is echoed by recent calls for '[i]nternational organizations and treaty frameworks' to be better equipped 'with a view to keeping pace with technological development'[75] and emphasis on the need for 'normative efforts'[76] and '[o]ur shared rules' to keep pace with such development.[77]

This race metaphor represents 'governmental oversight' as being 'inherently slow' compared to technological development[78] and invites us to regard the development of S&T as linear, following a unidirectional trajectory along a set timeline. The account is technologically deterministic in that it treats the development of S&T as evolving in an autonomous manner, independent of the socio-political and normative context.[79] Assumptions about linearity are widely held and remain in the background of many policies, but linear models of innovation have been much criticized and their explanatory capacity is limited in light of the complexity and interdependence ascribed to innovation in S&T. Recent innovation theories emphasize systemic, dynamic, non-linear processes involving a range of actors that interact through market mechanisms and flows of knowledge and influence within a particular institutional setting.[80]

The image of the race recognizes that technological and normative developments stand in some sort of relationship to each other. But rather than a competition of speed between two separate processes, against an objective criterion with a specific end point,[81] the social and the technical should be understood as constituting each other. Society, including politics and norms, are technically built and technology is socially and politically constructed.[82] Technology 'shapes not only the physical world but also the ethical, legal, and social environments in which we live and act'.[83] Focusing exclusively on 'normative efforts' as a means to rein in S&T developments through 'shared rules' in formal settings ('treaty frameworks') fails to account both for the social norms and values that, in any particular cultural setting, give rise to S&T developments, and for how such developments, in turn, influence norms and values.

The race metaphor also sidesteps a direct investigation into the causes and drivers of the accelerating pace of S&T developments relevant to disarmament. The focus in the Secretary-General's 2018 report and work by others, including our own, on specific developments of relevance to the means and methods of warfare, new weapons technologies or weapons applications of new technologies,[84] risks detracting from the structural, normative and political dimension of the process of innovation. The Secretary-General's report is silent on the lines of power through which military and weapons technologies develop.

As highlighted in the previous section, there is little engagement with the beliefs, ideas, values and visions that drive military innovation and weapons development. The very notion of the 'emergence' of new weapons denies any agency in the process, and describing the problem as one of 'weaponization' of S&T developments treats the latter as a priori politically and

THE CHOICE NOT TO ARTICULATE, IN MULTILATERAL DISARMAMENT DEBATES ON S&T, THE FORCES AND MECHANISMS THAT SUSTAIN AND ACCELERATE WEAPONS DEVELOPMENT DETRACTS FROM THE RESPONSIBILITY OF STATES AND CALLS INTO QUESTION WHAT WE, COLLECTIVELY, CAN HOPE TO ACHIEVE THROUGH POLITICAL ACTION IN THIS FIELD.

ethically neutral. In both cases, how and why new weapons come into being remains unexplored. The Secretary-General and UN Member States are quick to point out that 'many of the developments [in S&T] are occurring within the private sector and in academia',[85] whilst saying nothing about government decisions and incentive structures put in place to push and accelerate innovation in S&T with military and weapons applications, including through increasingly integrated systems of innovation.[86]

The choice not to articulate, in multilateral disarmament debates on S&T, the forces and mechanisms that sustain and accelerate weapons development detracts from the responsibility of states and calls into question what we, collectively, can hope to achieve through political action in this field. In the prevailing discourse on S&T, assertions that the normative and institutional framework for weapons control must 'keep ahead'[87] in a race against technology, and that agency is situated outside of the state are coupled with a 'breathless promissory discussion of emergent fields'[88] that emphasizes the transformative or disruptive potentials of technology. In combination, they tend to accentuate both the inevitability of S&T development and the impossibility of predicting and preventing negative outcomes. In the context of international security and disarmament, the process of innovation is allegedly an inescapable, largely uncontrollable force – i.e. ungovernable.

The construction of such a narrative by stakeholders in weapons control is a form of self-sabotage in that it cannot but undermine their collective capacity for ethical questioning and effective political action in favour of disarmament.[89] A different articulation of S&T developments and governance efforts might better serve the vision of sustainable peace and security outlined by the Secretary-General. In this vision, '[i]nternational approaches to regulate arms [are] integrated into broader work for prevention and sustainable development' with a view to 'bring[ing] the historical relationship between disarmament and development back to the forefront of international consciousness'.[90]

Formulating concerns about speed differentials in terms of 'the political process of seeking security at lower levels of armaments', as the Secretary-General did in his 1990 report,[91] would, at least, have the advantage of situating the issue explicitly in relation to disarmament as the end to be achieved. The emphasis on the political (as opposed to the technical) and on process (as opposed to outcome) opens up space for political action and helps direct attention not only to specific emerging weapons technologies, but to the systems maintained to produce them.[92] This invites critical questions about the underpinning logics of military applications of developments in S&T and the relentless development of new weapons, and about the roles and responsibilities of states, in particular, in the construction of this seemingly inexorable 'outpacedness'.

QUESTIONS FOR STAKEHOLDERS

- What factors shape how and why states pursue S&T developments for military applications or weapons? What factors shape the attributes of future weapons and military applications? How does the changing role of the military relative to other security agencies affect this?
- What are the patterns of investments in S&T by militaries? What are the types and purposes of the financed work? What are the patterns of (in)transparency in these regards? What systems of oversight are in place to assess their impact on disarmament? What is an appropriate relationship between the military and science?[93]
- If innovation in S&T is understood as a means of progress, what constitutes progress in the context of disarmament?
- What does 'keeping pace' with S&T developments look like exactly? What political action is required?
- How and why should states fight wars and engage in organized violence in the future? What roles should technologies play in future violence?
- What conception(s) of security and what visions about the role of S&T in organized violence are likely to promote S&T developments that support disarmament and accelerate its pace? How can these conditions be created?

GOVERNING S&T IN THE CONTEXT OF DISARMAMENT: BEYOND WAITING WITH VIGILANCE

‘GOVERNANCE ACTIVITIES ARE JUSTIFIED WITH REFERENCE TO THE COMMON GOOD, BUT THEY DO NOT NECESSARILY SERVE IT.’[94]

‘IF NO ONE GOVERNS, … NO ONE CAN BE MADE RESPONSIBLE.’[95]

ACCELERATED DELIBERATIONS?

In the face of the identified challenges, the UN Secretary-General urges the international community to ‘remain vigilant in understanding new and emerging weapon technologies that could imperil the security of future generations’[96] – a call echoed by the UN General Assembly.[97] He also identifies a number of ‘[p]rocesses for responding to developments’ in S&T with implications for security and disarmament.[98] Many of them deserve further attention and the support of stakeholders in weapons control. However, reporting annually on the accelerating pace of technology development and ‘remaining vigilant’ in understanding it does nothing to slow it down.[99] Nor does mapping out advances in weapons technologies foster resistance towards them.[100] Remarkably, none of the outlined processes directly addresses the causes of outpaced norm development. But elsewhere in his report, the Secretary-General suggests that ‘all existing multilateral efforts should be accelerated’.[101]

Whereas impatience with multilateral disarmament processes is a widely shared sentiment, the plan to accelerate these efforts flies in the face of everything we know about the UN and fails to recognize the role played by multilateral disarmament regimes as deliberative systems. It is by means of such systems that societies adjust to changing circumstances and new challenges.[102] They provide for ‘consideration of the acceptability, appropriateness and control of novel developments in, or impacting on, shared social and physical arenas’ and entail ‘both private and public modes of reflection, analysis and decision-making, and also the full range of practical, ethical, legal and political reasoning’.[103] As challenges posed by advances in S&T are not ‘matters of daily, self-interested decision-making’ but difficult and contentious issues that have a direct bearing on important socio-cultural and socio-political questions pertaining to our technological future, they require ‘informed, scrupulous thinking, generous provision for communication and debate – and time’.[104]

Debates about specific new weapons are embedded in much broader political struggles to define and redefine the limits of violence and dominant modes of governance. They not only reproduce existing power relations, but also become a site at which they are contested. This complicates quests for control.[105] Such deliberations will always be a protracted business,[106] and the need ‘for greater interaction between previously separated disarmament communities’ and for the involvement of other actors to elaborate risk

IN DISARMAMENT, THERE IS A RISK THAT S&T DEVELOPMENTS ARE ALWAYS EITHER TOO DISTANT AND UNCERTAIN OR TOO PROXIMATE AND SPECIFIC TO BE ADDRESSED.

mitigation strategies will further complicate finding common ground.[107] The goal, therefore, cannot be to accelerate deliberations, but to ensure that deliberations contribute to the development of 'sufficiently powerful and systematic understandings of technology for us to know where the possibilities lie for meaningful political action and responsible governance'.[108] Among other issues, this raises questions about the conditions (including institutional settings) conducive to iterative, adaptive and sustained political engagement with S&T developments and the timing of multilateral political intervention.

The UN Secretary-General's choice to concentrate in his report on 'applications that could feasibly be fielded within the next five years' privileges a near-term vision where the possibility for multilateral political action takes place relatively proximate to a weapon's operational deployment. Envisaging policy intervention at a moment in time where R&D has 'matured' into a soon-to-be-fielded weapon speaks to the challenge of scoping and assessing technologies in advance of concrete manifestations.[109] But once an application has solidified in this manner, space for meaningful disarmament action may be fast closing. On the other hand, the manifestation of harms caused by the use of a new weapon may facilitate political action and the imposition of legal constraints informed by such harms. However, responsible consideration of S&T in the context of disarmament must aim for political intervention before a new military technology has led to a humanitarian crisis.

In practice, this has proven difficult. Following the refusal in 2018 of States Parties to the Convention on Certain Conventional Weapons to retain S&T as a separate agenda item, one diplomat likened the situation to a 'Catch-22': in disarmament, there is a risk that S&T developments are always either too distant and uncertain or too proximate and specific to be addressed.[110] There is, of course, no reason to believe that the situation will be less vexing in the future. Choices about the timing of multilateral policy intervention therefore raise acute questions about what we understand our responsibility as stakeholders in weapons control to be in shaping our technological future.

GOVERNING THROUGH ETHICS?

To respond to relevant developments in S&T, the UN Secretary-General commits to engaging and working with scientists, engineers and industry to 'encourage responsible innovation in science and technology and to ensure they are applied for peaceful purposes'.[111] The appeal to responsible innovation and the turn to ethics in discussions on emerging technologies are very much *dans l'air du temps*. There has recently been a veritable 'ethics explosion' in the tech sector.[112]

Without exploring the theme in detail here (the Secretary-General does not expand on his understanding of 'responsible innovation'), one aspiration of responsible innovation is the alignment of research and development outcomes with societal values. Codes of conduct and the like are among the tools used for that purpose.

The practical impact of such texts has been called into question, however.[113] A recent analysis of AI ethics guidelines shows that there is 'a lot of virtue signalling going on', but few efforts to institute enforcement and governance mechanisms to operationalize them.[114] Ethical guidelines can serve to deflect criticism, avoid change and evade liability, whilst 'not ceding any power to regulate or transform the way technology is developed and applied'.[115] There is a risk that instead of asking fundamental ethical and political questions about whether a technology should be introduced, such texts delegate ethical agency and decision-making to a narrow circle of 'experts', who – espousing the same technologically deterministic progress narrative that has been criticized above – tend to frame technological progress as inevitable.[116]

Even with codes and laws in place, what is ethical remains open to debate.[117] Recent controversies surrounding Google's involvement in the US Department of Defense's Project Maven, Amazon's sale of its facial recognition software, Rekognition, to police agencies and Microsoft's collaboration with US Immigration and Customs Enforcement and its HoloLens contract with the US Army make it abundantly clear that scientists and technologists hold diverse views on what constitutes ethically acceptable applications of S&T.[118] These controversies are useful for understanding how technologies help or hinder the realization of a world in which people flourish, and what responsibilities individuals and institutions have for creating technologies that improve our lives. Especially in the context of disarmament, promoting 'responsible innovation' must involve engaging with the argument that all weapons research 'is ... morally wrong and cannot be justified.'[119]

The promotion of responsible innovation is no substitute for political action. Ongoing contestation of violent acts is needed to avoid that the limits of violence recede.[120] But ethics alone cannot answer all value questions and has never transformed technology for the good, not least because 'knowing the difference between good and bad is rarely enough, in itself, to incline us to the former'.[121] The recent corporate controversies do however help us understand what incentives and structures drive individuals and institutions not to build certain technologies and how collective action can change power dynamics.[122]

GOVERNING RESPONSIBLY

Claims about what constitutes appropriate research are bound up with the exercise of authority and expertise and the question of who is deemed to possess the relevant knowledge to inform policy-making. In recent years, special efforts have been made to bring diverse voices to bear on the role of S&T in the context of disarmament.[123] In particular, the views of younger people have been actively solicited and growing attention is given to questions of gender and race, suggesting that a wide range of knowledge is valued. In his report, the Secretary-General calls for the involvement of a broad range of actors, including from 'the private sector, non-governmental organizations and academia', in political deliberations, but he also stresses the importance of 'credible and reliable' 'scientific expertise' to inform policy-making.[124]

Other policy texts afford a similarly privileged position to 'scientific' knowledge. This reflects a general preference in modern societies for scientific forms of decision-making about issues related to S&T and echoes a vision of 'pure science' and apolitical innovation that has long dominated thought in the natural sciences.[125] The emphasis on responsible innovation as a process for responding to S&T developments relevant to disarmament reinforces the treatment of scientific and technical expertise, as well as ethical concerns, as separate from the political. However, 'there's no such thing as "just" an engineer'.[126]

The aforementioned corporate controversies have a direct bearing on political debates about new weapons technologies, for example in relation to autonomous weapons and armed drones. This invites questions about how scientific expertise is expected to contribute to the resolution of political problems,[127] and how expert disagreement is viewed in such a context.[128] For example, when scientists articulate ethical concerns about military applications of S&T and advocate for normative constraints on weapons development, are they still deemed 'reliable and credible' scientific experts who should 'support and inform policy deliberations',[129] or are they then viewed as activists or advocates and stripped of the special authority and influence granted to 'scientific' experts?

Expertise, including 'scientific' expertise is always circumscribed.[130] The interest in 'creating attendant groups of scientific experts to support and inform policy deliberations' as well as plans to 'enhance cooperation with the private sector, non-governmental organizations and academia'[131] invite further reflection on patterns of representation and modes of participation in multilateral policy-making in the area of weapons control. More thought should be given to what kinds of questions need a specialist answer, what kinds of questions should be put to 'scientific' experts, how 'credible and reliable' experts are identified and by whom, and how scientific advice should be organized and managed in relation to political processes. Widening the notion of expertise to include various knowledgeable people (including from medical associations, survivor groups, environmental actors and the like) will produce more 'socially robust knowledge'.[132] Acknowledging that different kinds of knowledge are relevant in the policy process, and that technocratic risk assessments and cost-benefit analyses need to be complemented with approaches that 'make explicit the normative that lurks within the technical' are instrumental to achieving 'good governance'.[133]

'Governance and regulation are, in part, about the allocation of responsibility'.[134] With the multiplication of regulatory and governance activities, and with the increasing complexity of regulatory constellations in the global policy space, responsibilities tend to get diffused and dispersed.[135] When stakeholders in weapons control locate agency within academia and the private sector and emphasize responsible innovation, they shift

AS LONG AS STATES CLAIM THE MONOPOLY ON THE USE OF FORCE, THEY MUST SHOULDER THE PRIMARY RESPONSIBILITY FOR THE CONTROL OF THE TECHNOLOGIES OF VIOLENCE.

responsibility for addressing the drivers of S&T developments away from governments and inter-governmental institutions towards innovators. This creates an expectation that scientists and private-sector developers not only govern risk related to their research practice but also to down-stream technological outputs in relation to issues of use, misuse and militarization.[136] Framing innovators as capable of and responsible for monitoring and managing S&T developments directs attention to individual choices and masks the structures within which these are made. This may not only place unfair demands on innovators, but, as discussed above, avoids an earnest engagement with the forces sustaining ongoing weapons development.

As long as states claim the monopoly on the use of force, they must shoulder the primary responsibility for the control of the technologies of violence. Contemporary theories of innovation clearly imply a role for governments and (inter-)governmental actors in the creation of incentives for different types and rates of innovation. In practice, however, UN Member States have thus far shown limited appetite for dedicating time and resources to the consideration of S&T developments in existing weapons control bodies[137] and have cautioned against creating new ones.[138] They have stressed the importance of ensuring that 'efforts to govern new weapons technologies or weapons applications' do not 'hamper the economic and technological growth and innovation of any State'.[139] In this optic, governance efforts are portrayed as a potential impediment to the attainment of social goods. Portraying deliberation and regulation of new weapons as an encumbrance to be overcome is politically debilitating. It occludes that both technology and law order society and constrain human possibilities – that 'technology functions as an instrument of governance'.[140]

At the same time, though, the renewed interest in the role of S&T in the context of disarmament reaffirms the responsibility of stakeholders in multilateral weapons control. The adoption of UN General Assembly resolutions and the production of a Secretary-General report on the topic, as well as calls for S&T developments to be addressed within existing multilateral mechanisms and instruments, attest to the conviction that these regimes should play a central role in policy responses. The recent corporate controversies about military applications of S&T underscore the importance of political deliberation about shared principles in terms of ethical content and process[141] as well as the need for laws and policies. Multilateral weapons control institutions can continue to play an important role in setting common standards. To govern responsibly, stakeholders in multilateral weapons control should facilitate ongoing deliberation, not only on uses and abuses of innovations, but also on whether they should be introduced in the first place.

QUESTIONS FOR STAKEHOLDERS

- What are the prospects and means for understanding developments in S&T in multilateral disarmament? Is there agreement on the scope and objective of S&T consideration in that context? Is there a common understanding of what technology assessment or review involves?

- What kinds of knowledge are necessary to create a socially robust understanding of the security implications of S&T developments? Who possesses that knowledge? What can 'scientific' expertise contribute? What can practical, non-scientific and experience-based expertise contribute?

- What constitutes responsible innovation in S&T? What are the purposes and limits of responsible innovation strategies in the context of disarmament? How, concretely, can applications that support disarmament be promoted?

- How should different actors (the public, governments, innovators, etc.) contribute to addressing security and disarmament implications of S&T developments? What role should different tools (national-level innovation strategies, scientific risk assessments, ethical codes, etc.) play?

- How should multilateral weapons control intersect with S&T governance and other global governance agendas? What institutional settings are most conducive to realizing this vision?

CONCLUDING REMARKS

'[P]OSITIVE VISIONS ARE EVERYWHERE IF YOU CARE TO LOOK. AND IF SOMEONE HAS NOT CARED OR BOTHERED TO LOOK, WE SHOULD ASK, "WHY?"'[142]

It is widely acknowledged that '[t]echnology isn't just something that happens to us; it's something we can decide to build and to use, or not'.[143] The stories that we tell ourselves about the past and the visions we hold about the future play an important role in shaping the direction and the pace of S&T development. Programmatic texts, such as Agenda 2030 hold the promise of human betterment and are stories about change. Telling such stories requires the ability and willingness to imagine alternatives to reality as we know it. They therefore invite us to question underlying structures and assumptions of power.

For stakeholders in multilateral weapons control, the renewed interest in S&T in the context of international security and disarmament is an opportunity to collectively articulate visions of a more peaceful, less violent future and to 'devalue the role of military options in seeking security'.[144] At present, it is unclear whether the 'disarmament community' is united in a shared vision. Stakeholders appear unable or unwilling to recommit to the idea of disarmament enshrined in the UN Charter and the outcome document of SSOD-I. The authoritative discourse is such that those who dare articulate this aspiration in a weapons control context risk being disqualified as naïve and inexpert, or dismissed as engaging in insincere rhetoric. The near-exclusive preoccupation of stakeholders with the management and control of risks posed by specific S&T developments leaves little space for debate on technological futures.[145]

This is not to suggest that we can 'fantasize our way out of this'.[146] It is meant as an invitation to critically reflect on the deeper structural causes of disarmament's stagnation. These are well known, and this paper does not purport to add novel insights. It does, however, raise concern that the S&T narrative under development in the context of disarmament comes with obvious risks: unquestioningly reproducing beliefs about the inevitability of weapons development and perpetuating politically debilitating narratives accords with and entrenches, rather than challenges, the status quo. Today, the dominant narrative on S&T in the context of disarmament distracts from attending to the structural causes of the lack of progress in disarmament and creates low expectations about the prospect of multilateral weapons control, offering irresponsibility as a strategy.

There is evidently an urgent need to address developments in S&T with implications for international security and disarmament. How we address them matters greatly. Although they may not be as exciting or novel as futuristic weapons,

THE RENEWED INTEREST IN S&T IN THE CONTEXT OF INTERNATIONAL SECURITY AND DISARMAMENT IS AN OPPORTUNITY TO COLLECTIVELY ARTICULATE VISIONS OF A MORE PEACEFUL, LESS VIOLENT FUTURE

questions about security conceptions and appropriate military-civilian relations in innovation systems are pressing 'this-world' issues that require focused attention. Consideration of S&T opens up space for critiquing technology, questioning proposed visions of future war, debating different outlooks on the role of technologies in organized violence and deliberating about the common goods that innovation in S&T is meant to realize. The Secretary-General's Agenda for Disarmament provides a valuable starting point in this regard.

Establishing 'a clear and credible vision for sustainable security'[147] will require conceptualizing existing disarmament institutions, actors and processes in new ways and rethinking their contribution to S&T governance in the global policy space. The *lenteur* of disarmament deliberations does not mean that weapons control regimes have nothing to offer. Insofar as S&T developments are understood as a potential challenge to existing systems of oversight and control, the collective assessment of S&T in weapons control settings reasserts the centrality of existing regimes and regulations for the future governance of S&T. Aside from their potential to set formal standards (often unrealized in practice), multilateral weapons control forums enable processes for deliberated, agreed forms of order, capable of conferring legitimacy through broad-based conversations. Implicating a variety of actors and drawing on diverse knowledge and values will be essential to making policies that serve the common good.

Weapons control debates help stabilize policy discourse, notably, through storytelling. They can help 'organize dialogues, foster meanings, beliefs and identities among the relevant actors, and influence what actors think and do'.[148] Hence, the importance of critically reflecting on the stories that are being told, who they empower and who is empowered to tell them.

NOTES

1 UNGA Res 72/28, 11 December 2017; UNGA Res 73/32, 11 December 2018.

2 Report of the Secretary-General on current developments in science and technology and their potential impact on international security and disarmament efforts, UN doc A/73/177, 17 July 2018.

3 Ibid, §3.

4 UN Office for Disarmament Affairs (UNODA), *Securing Our Common Future: An Agenda for Disarmament*, 2018, §3, www.un.org/disarmament/sg-agenda. UNGA Res 73/32 contains similar language: 'remain vigilant in understanding new and emerging developments in science and technology that could imperil international security, and underlines the importance of Member States engaging with experts from industry, the research community and civil society in addressing this challenge'.

5 These bulletins are annexed to this paper and are also available for download from our website: www.article36.org/publications/.

6 A. N. Whitehead, *Science and the Modern World: Lowell Lectures, 1925, 1926,* p. 259, http://archive.org/details/b29978531.

7 UNGA Res 72/28.

8 Ibid.

9 Report of the Secretary-General on current developments in science and technology.

10 Ibid, §2.

11 Ibid, §3.

12 UNGA Res 73/32.

13 Given the limited scope of this paper, the analysis presented draws on a relatively small number of texts. This work could be further developed through a more extensive investigation.

14 This paper is meant to support the practice of foresight which aims to promote the exploration of multiple alternative futures in order to avoid converging too quickly on a particular vision of the future (due to group dynamics, for example) or failing to make plans due to the uncertainty inherent in the future. See, e.g., C. Tully, *Applying Foresight and Alternative Futures to the United Nations Development Assistance Framework*, United Nations Development Group, 2016, https://undg.org/wp-content/uploads/2016/10/Final-DOCO-foresight-paper.pdf, p. 4).

15 M. McLuhan et al, *The Medium Is the Massage: An Inventory of Effects*, 1967, p. 25, https://ia902302.us.archive.org/28/items/pdfy-vNiFct6b-L5ucJEa/Marshall%20McLuhan%20-%20The%20Medium%20is%20The%20Massage.pdf.

16 Report of the Secretary-General on current developments in science and technology, §2. Such a sweeping normative statement evokes Tierney's 'technological fetishism' (T. F. Tierney, *The Value of Convenience: A Genealogy of Technical Culture,* 1993) and Postman's 'Technopoly—the submission of all forms of cultural life to the sovereignty of technique and technology' (N. Postman, *Technopoly: The Surrender of Culture to Technology,* 1993, p. 52, https://www.collier.sts.vt.edu/1504/pdfs/technopoly-neil-postman.pdf). See also A. Russell and L. Vinsel, 'Hail the Maintainers', *Aeon*, 7 April 2016, https://aeon.co/essays/innovation-is-overvalued-maintenance-often-matters-more: 'Entire societies have come to talk about innovation as if it were an inherently desirable value, like love, fraternity, courage, beauty, dignity, or responsibility. Innovation-speak worships at the altar of change, but it rarely asks who benefits, to what end?'.

17 UNODA, *Securing Our Common Future*, p. 51.

18 United Nations, UN Secretary-General's Strategy on New Technologies, September 2018, http://www.un.org/en/newtechnologies/images/pdf/SGs-Strategy-on-New-Technologies.pdf.

19 Sustainable Development Goals Knowledge Platform, 'Technology Facilitation Mechanism', https://sustainabledevelopment.un.org/TFM/.

20 International Telecommunication Union, 'AI for Good Global Summit 2018', https://www.itu.int/en/ITU-T/AI/2018/Pages/default.aspx.

21 UNGA Res 72/28; UNGA Res 73/32.

22 UNODA, *Securing Our Common Future,* pp. 51, 54; Report of the Secretary-General on current developments in science and technology, §§3, 95.

23 UNGA Res 72/28; UNGA Res 73/32.

24 Report of the Secretary-General on current developments in science and technology, §70. ; UNODA, Securing Our Common Future, p. 5.

25 Ibid, §83. See, e.g., CTBTO, 'SnT 2019', CTBT Science and Technology Conference, 24-28 June 2019, Vienna, Austria, https://www.ctbto.org/SnT2019/.

26 A. Grissom, 'The Future of Military Innovation Studies', 29(5) *Journal of Strategic Studies* (October 2006) 907.

27 S. Griffin, 'Military Innovation Studies: Multidisciplinary or Lacking Discipline?', 40(1–2) *Journal of Strategic Studies* (2 January 2017) 217.

28 E.g., Reply from Switzerland, Report of the Secretary-General on current developments in science and technology, p. 39. Similarly, ibid, §15: 'some degree of autonomy in military systems could have security benefits'.

29 See E. Schwarz, *Death Machines: The Ethics of Violent Technologies*, 2018, for a recent critique of the 'ethical weapons' trope.

30 The disagreement concerns, notably, nuclear-armed states' commitment and legal obligation to pursue nuclear disarmament, as enshrined, e.g., in Art VI, Treaty on the Non-Proliferation of Nuclear Weapons, 1968.

31 Statement by Nepal, UN General Assembly First Committee, 11 October 2018, http://reachingcriticalwill.org/images/documents/Disarmament-fora/1com/1com18/statements/11Oct_Nepal.pdf.

32 Reply from Switzerland, pp. 40–41.

33 See V. P. Kotchetkov, 'Science and Technology Policy in the United Nations System: A Historical Overview', R. Arvanitis (ed.), *Science and Technology Policy*, Encyclopedia of Life Support Systems, vol 2, 2009; E. B. Court et al, 'Nanotechnology and the Developing World', in H. A. M. J. ten Have (ed.), *Nanotechnologies, Ethics and Politics*, 2007, p. 155: 'Science & Technology (S&T) and Research & Development (R&D) are disproportionately concentrated in industrialized nations and applied to their priorities'; M. Imaz and C. Sheinbaum, 'Science and Technology in the Framework of the Sustainable Development Goals', 14(1) *World Journal of Science, Technology and Sustainable Development* (2017), https://www.emeraldinsight.com/doi/full/10.1108/WJSTSD-04-2016-0030. Recent resolutions include: UNGA Res 72/228, 18 January 2018, on Science, technology and innovation for development, and UN Economic and Social Council Res 2018/29, 6 August 2018 on Science, technology and innovation for development.

34 UNGA Res 73/32.

35 UNGA Res 72/28.

36 Reply from Switzerland, p. 38.

37 Consider, for example, that it is almost impossible to debate autonomous weapons without someone making reference to the benefits of self-driving cars or robotic vacuum cleaners, whereas the implications of weapons development for the environment and social justice are routinely excluded from such debates. Disarmament policy makers saying that military and weapons applications of advances in S&T pose serious risks, whilst pointing to the health, employment or infrastructure benefits of S&T should strike us as just as absurd as if human rights policy makers were to say that human trafficking is a serious human rights concern, whilst pointing out that transportation is great for moving people and goods around; or if development policy makers were to say that forced labour robs people of their human dignity, whilst pointing out that labour enables the development of new skills; or if health policy makers were to say that sniffing glue poses severe health risks, whilst pointing out that glue is great for sticking things to other things.

38 On how such attempts to reassure us 'about the fundamentally progressive and beneficent character of technological change' feed a narrative of intended versus unintended consequences of technologies, see S. Jasanoff, *The Ethics of Invention: Technology and the Human Future*, 2016, Adobe Digital edn, pp. 10–11.

39 Final document of the Tenth Special Session of the General Assembly, UN doc S-10/2, 1978, §11.

40 Ibid, §§39, 77.

41 UNGA Res 43/77 (A), 7 December 1988.

42 At that time, the UN Secretary-General was mandated to follow future scientific and technological developments, especially those which have potential military applications, and to evaluate their impact on international security. The issue has since been on the agenda of the General Assembly's First Committee.

43 Report of the Secretary-General on scientific and technological developments and their impact on international security, UN doc A/45/568, 17 October 1990, §§9–11. The report envisaged that the UN should serve as a 'catalyst and a clearing-house' in technology assessment efforts and proposed a framework and criteria for the assessment of new technologies, notably with a view to examining whether they 'call into question the existing international agreements on arms limitation or the tacit understandings crucial for their adherence' (ibid, §86). It proposed the following criteria: 'a) Will they offer new military options either by significantly improving known weapons or by creating new weapon systems? b) What will be their impact on crisis management in peace and during conflict? c) Will they promote better means of verification or weapons disposal? d) Will they create a new set of issues for ongoing negotiations?' (Ibid). Although UN Member States subsequently tasked the Secretary-General with elaborating a framework for technology assessment (UNGA Res 45/60, 4 December 1990), and UNODA carried out initial consultations (Report of the Secretary-General on scientific and technological developments and their impact on international security, UN doc A/47/355, 10 August 1992, §6), action was postponed due to ongoing S&T considerations in the Disarmament Commission (which, after several years of work, produced no tangible results).

44 B. Edwards, *Insecurity and Emerging Biotechnology: Governing Misuse Potential*, 2019, p. 16.

45 See, e.g., Y. Ezrahi, 'Science and the State', *International Encyclopedia of the Social & Behavioral Sciences*, 2nd edn, 2015.

46 Report of the Secretary-General on scientific and technological developments and their impact on international security, UN doc A/49/502, 12 October 1994.

47 Ibid, §14. The report takes into account consultations and deliberations within the framework of the Disarmament Commission. It also contains a section entitled Technology Assessment (§§18–26), but fails to provide a framework for technology assessment. Instead, it proposes to narrow the terms of the debate to proliferation concerns ('Would the suppliers and clients be better or worse off without the transfer? Are there some areas where technological cooperation would yield better results than doing it alone? What is the range of options available for ensuring that the end use of technology is for the purpose intended in the transfer?' (ibid, §17)), and recasts the UN's role as one of 'provid[ing] a political milieu for policy adaptation' through procedures for consensus-building, with a view to assisting member states to adopt 'cooperative policies for influencing the nature and direction of technological change' (ibid, §28).

48 Ibid, §8.

49 Ibid, §10.

50 Ibid, §12. This narrative taps into a concept of 'technological innovation' that, after World War II, became increasingly understood as 'commercialized invention', 'a tool to reduce lags or gaps in productivity'. This concept of innovation was gradually embraced by international organizations and governments 'as a solution to economic problems and international competitiveness'.

51 National Security Strategy of the United States of America, December 2017, p. 20, https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf. In the context of regional security, see, e.g., Council of the European Union, Proposal for a Regulation of the European Parliament and of the Council Establishing the European Defence Fund, Interinstitutional File 2018/0254(COD), 15 November 2018, §23: 'The promotion of innovation and technological development in the Union defence industry should take place in a manner coherent with the security and defence interests of the Union', http://data.consilium.europa.eu/doc/document/ST-14094-2018-REV-1/en/pdf.

52 National Security Strategy of the United States of America, pp. 3, 26. See also E. Kania, 'Swarms at War: Chinese Advances in Swarm Intelligence', 17(9) *China Brief* (6 July 2017): 'The [Chinese People's Liberation Army]'s strategic objective of strengthening the military through science and technology … will take advantage of a coordinated national strategy of "innovation-driven development." The PLA seeks to "overtake [the U.S. military] around a corner" … through cutting ahead, rather than taking the same track, by achieving technological, conceptual, and organizational innovation in strategic frontier … technologies', https://jamestown.org/program/swarms-war-chinese-advances-swarm-intelligence/.

53 'In order to maintain a lead, speed needs to be picked up in some areas, including the pace at which organisations can buy and field relevant weapons and systems, as well as the speed with which defence ministries and armed forces are able to adapt, innovate and integrate change. The West could look to maintain a technological lead, and it is likely that investments will increase in advanced-technology areas as key Western states try to retain or obtain an advantage' (IISS, 'The Speed of War: Faster Weapons; Faster Organisations', Strategic Survey 2018: The Annual Assessment of Geopolitics).

54 K. I. Bjerga and T. L. Haaland, 'Development of Military Doctrine: The Particular Case of Small States', 33(4) Journal of Strategic Studies (1 August 2010). The perception of a technology, its role in organized violence, potential specific applications and whether or not it is seen as a threat all differ from one state to another and are shaped by military strategic culture (D. Adamsky, *The Culture of Military Innovation: The Impact of Cultural Factors on the Revolution in Military Affairs in Russia, the US, and Israel*, 2010).

55 Edwards, *Insecurity and Emerging Biotechnology*, p. 27.

56 Ibid, p. 91.

57 See, e.g., M. Brehm and A. de Courcy Wheeler, *Swarms,* Article 36, March 2019, http://www.article36.org/wp-content/uploads/2019/05/swarms.pdf. 'To harness the power of swarms', militaries are encouraged to 'develop new technology, but also [to] modify training, doctrine and organizational structures to adapt to a new technological paradigm' (P. Scharre, *Robotics on the Battlefield Part II: The Coming Swarm*, Center for a New American Security, October 2014, p. 41, https://s3.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf?mtime=20160906082059). The authors of an earlier study 'advance[d] the idea of swarming … as a definitive doctrine that will encompass and enliven both cyberwar and netwar' and argued that 'profound shifts will have to occur to nurture this new "way of war"' (J. Arquilla and D. Ronfeldt, *Swarming & the Future of Conflict*, RAND, 2000, pp. iii, vii, https://www.rand.org/content/dam/rand/pubs/documented_briefings/2005/RAND_DB311.pdf).

58 On how the discourse of 'better weapons' occludes critical ethical questioning, see, e.g., *Schwarz, Death Machines*.

59 'The pace of technological change will accelerate the speed of battle and raise the demand for yet quicker weapons' (Report of the Secretary-General on current developments in science and technology, §§90, 93).

60 UNODA, *Securing Our Common Future*, p. 51.

61 S. Jasanoff and S.-H. Kim, *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*, 2015, p. 11.

62 UNESCO promotes the development of 'futures literacy', which it describes as a capability that allows people to better understand the role that the future plays in what they see and do (UNESCO, 'Futures Literacy', https://en.unesco.org/themes/futures-literacy). Consider also Tully, *Applying Foresight and Alternative Futures to the United Nations Development Assistance Framework*.

63 See, e.g., UN, *Global Sustainable Development Report*, 2016, Chapter 3, https://sustainabledevelopment.un.org/content/documents/10789Chapter3_GSDR2016.pdf; Consider also the ongoing debate about whether military-security assistance should be considered part of financing for SDG 16 under the OECD's 'Total Official Support for Sustainable Development' (Saferworld and others, Tracking Support to Sustainable Development Goals – the Case of Peace and Security: A submission from civil society organisations working on peace and sustainable development, March 2019, https://www.saferworld.org.uk/downloads/pubdocs/cso-submission-on-tossd-security-assistance-march-2019.pdf).

64 W. E. Bijker, 'Technology, Social Construction of', *International Encyclopedia of the Social & Behavioral Sciences*, 2015, p. 137.

65 See, in particular, G. E. Marchant et al (eds), *The Growing Gap Between Emerging Technologies and Legal-Ethical Oversight: The Pacing Problem*, 2011.

66 J. Whitman, 'The Challenge to Deliberative Systems of Technological Systems Convergence', 20(4) *Contemporary Security Policy* (2007) 329.

67 UNGA Res 72/28; UNGA Res 73/32.

68 UNODA, *Securing Our Common Future*, p. 51.

69 Report of the Secretary-General on current developments in science and technology.

70 Reply from Jordan, ibid, p. 28.

71 Reply from Switzerland, p. 38.

72 Reply from Japan, Report of the Secretary-General on current developments in science and technology, p. 26.

73 In the context of 'biological risk and security', the concern that 'future biological risks are … more rapidly developed and deployed' (D. Endy, 'Strategy for Biological Risk & Security', 2003, p. 3, https://dspace.mit.edu/bitstream/handle/1721.1/30595/BioRisk.v2.pdf?sequence=1) has at times been framed as 'centring on a race between the inevitable development of technological capabilities which might make the hostile use of biotechnology more likely and effective, and the challenge of developing technical solutions to manipulate biological agents and abilities to detect, respond to and mitigate these effects' (Edwards, *Insecurity and Emerging Biotechnology*, p. 52). In relation to S&T in the context of disarmament, this orientation is reflected in the standing invitation extended to UN Member States 'to continue efforts to apply developments in science and technology for disarmament-related purposes' (UNGA Res 73/32).

74 K. W. Abbot, 'Introduction: The Challenges of Oversight for Emerging Technologies', G. E. Marchant et al (eds), *Innovative Governance Models for Emerging Technologies*, 2013, p. 3.

75 Reply from Switzerland, p 40.

76 Report of the Secretary-General on current developments in science and technology, §70.

77 UN General Assembly, 12th Plenary Meeting, UN doc A/73/PV.12, 28 September 2018.

78 Abbott, 'Introduction', p. 4.

79 Both heralding S&T as a progressive force for good and criticizing it for being out of control or forcing unpredictable social change are normative, technologically deterministic accounts (R. R. Kline, 'Technological Determinism', *International Encyclopedia of the Social & Behavioral Sciences*, 2015). Whilst critiques of particular weapons technologies, such as efforts to prevent the emergence of 'killer robots', deny the social beneficence of that S&T application, they, too, feed into a technological determinist vision. On 'The Determinist Fallacy', see, Jasanoff, *The Ethics of Invention*, pp. 6–11.

80 P. Greenacre et al, *Innovation Theory: A Review of the Literature*, Imperial College Centre for Energy Policy and Technology (ICEPT) Working Paper, May 2012, https://pdfs.semanticscholar.org/ef2e/41da03f09049a251650d0fa19ea3415e0054.pdf, and R. Mawhood et al, *Supporting Renewable Energy in Latin America and the Caribbean: Lessons to Learn From Innovation Theory*, ICEPT Working Paper, May 2013, https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/ICEPT---Supporting-RE-in-LAC---Lessons-to-learn-from-innovation-theory.pdf.

81 For a similar critique, see V. Dignum, 'There Is No AI – Race and If There Is, It's the Wrong One to Run', ALLAI, allai.nl/there-is-no-ai-race/.

82 Bijker, 'Technology, Social Construction of', p. 139.

83 Jasanoff, *The Ethics of Invention*, p. 4.

84 Report of the Secretary-General on current developments in science and technology, §2.

85 Ibid, §90.

86 'Private industry owns many of the technologies that the government relies upon for critical national security missions. The Department of Defense and other agencies will establish strategic partnerships with U.S. companies to help align private sector R&D resources to priority national security applications. … The United States must … field new technologies at the pace of modern industry. Government agencies must shift from an archaic R&D process to an approach that rewards rapid fielding and risk taking' (National Security Strategy of the United States of America, p. 21); 'Each proposal shall be assessed on the basis of the following criteria: (a) contribution to excellence or potential of disruption in the defence domain … ; (b) contribution to … new promising future technological improvements or the application of technologies or concepts previously not applied in defence sector … ; (c) contribution to the competitiveness of the European defence industry … ; (d) contribution to … the security and defence interests of the Union' (European Commission, Proposal for a Regulation of the European Parliament and of the Council Establishing the European Defence Fund, Art 13). Consider also China's policy of civil-military fusion or integration, intended to promote the joint development of technology by the military, academia and industry (G. Levesque and M. Stokes, *Blurred Lines: Military-Civil Fusion and the 'Going Out' of China's Defense Industry*, Pointe Bello, December 2016, https://static1.squarespace.com/static/569925bfe0327c837e2e9a94/t/593dad0320099e64e1ca92a5/1497214574912/062017_Pointe+Bello_Military+Civil+Fusion+Report.pdf). See also E. A. Laksmana, 'Threats and Civil–Military Relations: Explaining Singapore's "Trickle down" Military Innovation', 33(4) *Defense & Security Analysis* (2 October 2017) 348: 'evolutionary peacetime military innovation is more likely to occur in a state with a unified civil–military relation and whose military faces a high-level diverse set of threats'.

87 UNODA, *Securing Our Common Future*, p. 51.

88 Edwards, *Insecurity and Emerging Biotechnology,* p. 6. See also A. Nordmann and A. Schwarz, 'Lure of the "Yes": The Seductive Power of Technoscience', M. Kaiser et al (eds) *Governing Future Technologies: Nanotechnology and the Rise of an Assessment Regime*, 2010.

89 That technological progress is inevitable and that resistance is futile are widely held, but flawed ideas. Jasanoff, *The Ethics of Invention*, p. 113, explains that '[a] trio of commonly held but flawed beliefs [technological determinism, technocracy, and unintended consequences], each suggesting that technologies are fundamentally unmanageable, and therefore beyond ethical analysis and political supervision, long impeded systematic thinking about the governance of technology'.

90 UNODA, *Securing Our Common Future*, p. 7.

91 Report of the Secretary-General on scientific and technological developments and their impact on international security, 1990, §9.

92 Edwards, *Insecurity and Emerging Biotechnology,* p. 2.

93 Ibid, p. 26.

94 M. Zürn, 'Global Governance as Multi-Level Governance', D. Levi-Faur (ed.), *The Oxford Handbook of Governance*, 2012, Adobe Digital edn, p. 755.

95 Zürn, 'Global Governance as Multi-Level Governance', p. 765.

96 Report of the Secretary-General on current developments in science and technology, §3.

97 UNGA Res 73/32, §2: 'Calls upon Member States to remain vigilant in understanding new and emerging developments in science and technology that could imperil international security'.

98 Report of the Secretary-General on current developments in science and technology, §§3, 92–97.

99 On the attitude of 'waiting-with-vigilance' coupled with enthusiasm about 'the responsible development of something that is yet to take on definite shape and meaning', see Nordmann and Schwarz, 'Lure of the "Yes": The Seductive Power of Technoscience', p. 256.

100 See Tierney, *The Value of Convenience*, p. 3.

101 UNODA, *Securing Our Common Future*, p. 51.

102 Whitman, 'The Challenge to Deliberative Systems of Technological Systems Convergence', 330.

103 Ibid.

104 Ibid, 334.

105 Edwards, *Insecurity and Emerging Biotechnology*, pp. 8–9.

106 Whitman, 'The Challenge to Deliberative Systems of Technological Systems Convergence', 336.

107 Reply from Switzerland, p. 40.

108 Jasanoff, *The Ethics of Invention*, p. 13.

109 When the time is right for policy intervention is, of course, a matter of debate. Whereas there is widespread agreement today that the time is right for multilateral policy action on hypersonic weapons, regulatory constraints on autonomous weapons are deemed overdue by some and premature by others (see, e.g., M. Brehm and A. de Courcy Wheeler, *Hypersonic Weapons*, Article 36, February 2019, http://www.article36.org/wp-content/uploads/2019/03/hypersonic-weapons.pdf).

110 Disarmament policy makers are not alone in grappling with the indeterminacy of S&T developments. The members of the UN Human Rights Committee recently debated whether it was time to update General Comment no 16 (Right to Privacy), dating from 1988. They decided against it, with several committee members arguing that any comment they could produce would likely be outdated by the time of its adoption in light of the technological developments underway. Committee member Santos Pais (from 2:05:39) compared the right to privacy to one's shadow: 'when we pursue it, it runs before us, and when we don't look, it's right behind us' (Human Rights Committee, 3561st Meeting, 124th Session, 30 October 2018 (Part IV), UN Web TV, http://webtv.un.org/meetings-events/human-rights-treaty-bodies/human-rights-committee/watch/part-four-general-comment-3561st-meeting-124th-session-of-human-rights-committee/5855732116001/?term=).

111 Report of the Secretary-General on current developments in science and technology, §97.

112 J. Vincent, 'The Problem with AI Ethics', *The Verge*, 3 April 2019, https://www.theverge.com/2019/4/3/18293410/ai-artificial-intelligence-ethics-boards-charters-problem-big-tech.

113 M. Whittaker et al, *AI Now Report 2018*, AI Now Institute, December 2018, p. 31: 'Empirical study of the use of these codes is only beginning, but preliminary results are not promising', https://ainowinstitute.org/AI_Now_2018_Report.pdf.

114 Algorithm Watch, *The AI Ethics Guidelines Global Inventory*, 9 April 2019, https://algorithmwatch.org/en/project/ai-ethics-guidelines-global-inventory/.

115 M. Whittaker et al, *AI Now Report 2018*, p. 31.

116 Ibid.

117 Schwarz, *Death Machines*, ebook location 456.

118 S. Shane and D. Wakabayashi, '"The Business of War": Google Employees Protest Work for the Pentagon', *The New York Times*, 4 April 2018, https://www.nytimes.com/2018/04/04/technology/google-letter-ceo-pentagon-project.html; K. Conger, 'Amazon Workers Demand Jeff Bezos Cancel Face Recognition Contracts With Law Enforcement', *Gizmodo*, 21 June 2018, https://gizmodo.com/amazon-workers-demand-jeff-bezos-cancel-face-recognitio-1827037509; S. Frenkel, 'Microsoft Employees Protest Work With ICE, as Tech Industry Mobilizes Over Immigration', *The New York Times*, 19 June 2018, https://www.nytimes.com/2018/06/19/technology/tech-companies-immigration-border.html; C. Lecher, 'Microsoft Workers' Letter Demands Company Drop Army HoloLens contract', *The Verge*, 22 February 2019, https://www.theverge.com/2019/2/22/18236116/microsoft-hololens-army-contract-workers-letter.

119 J. Forge, 'The Case Against Weapons Research', in R. Luppicini (ed.), *The Changing Scope of Technoethics in Contemporary Society*, 2018, p. 132.

120 Schwarz, *Death Machines*, ebook location 4712.

121 D. Susser, 'Ethics Alone Can't Fix Big Tech', *Slate*, 17 April 2019, https://slate.com/technology/2019/04/ethics-board-google-ai.html.

122 Ibid.

123 E.g., UNODA, 'Conference on Disarmament and Civil Society Dialogue: Frontier Issues', Geneva, 17 August 2018, https://www.unog.ch/80256EDD006B8954/(httpAssets)/ADB92782FF8AD2FBC12582EB005E669A/$file/Conference+on+Disarmament+and+Civil+Society_Programme.pdf; Geneva Disarmament Platform, '2018 Disarmament Essay Contest', http://www.disarmament.ch/wp-content/uploads/2018/05/Flyer-essay-contest-final.pdf.

124 Ibid, §§90, 93, 95.

125 See Edwards, *Insecurity and Emerging Biotechnology*, pp. 6, 16–17 (on the myth of pure science), and Jasanoff, *The Ethics of Invention*, p. 9 (on the myth of technocracy).

126 Tweet by A. L. Hoffmann (@annaeveryday), 1 May 2018, https://twitter.com/annaeveryday/status/991339883246403585.

127 Edwards, *Insecurity and Emerging Biotechnology*, p. 7. See also *Knowledge and Diplomacy: Science Advice in the United Nations System*, 2002; S. Jasanoff, 'Technologies of Humility: Citizen Participation in Governing Science', 41 *Minerva* (2003), http://sciencepolicy.colorado.edu/students/envs_5100/jasanoff2003.pdf; H. Nowotny, 'Democratising Expertise and Socially Robust Knowledge', 30(3) *Science and Public Policy* (2003) 152.

128 B. Wynne and M. Lynch, 'Science and Technology Studies: Experts and Expertise', *International Encyclopedia of the Social & Behavioral Sciences*, 2015, p. 206.

129 Report of the Secretary-General on current developments in science and technology, §93.

130 Wynne and Lynch, 'Science and Technology Studies', p. 206.

131 Report of the Secretary-General on current developments in science and technology, §§93, 95.

132 Nowotny, 'Democratising Expertise and Socially Robust Knowledge', 151–156.

133 Ibid, 153; Jasanoff, 'Technologies of Humility', 240.

134 M. L. Djelic and K. Sahlin, 'Reordering the World: Transnational Regulatory Governance and its Challenges', D. Levi-Faur (ed.), *The Oxford Handbook of Governance*, 2012, Adobe Digital edn, p. 776. On the notion of 'global policy space', see W. D. Coleman, 'Governance and Global Public Policy' D. Levi-Faur (ed.), *The Oxford Handbook of Governance*, 2012, Adobe Digital edn, p 705.

135 Djelic and Sahlin, 'Reordering the World', Adobe Digital edn, p. 776.

136 Edwards, *Insecurity and Emerging Biotechnology*, p. 90.

137 E.g., in 2016, the Fifth Review Conference of the High Contracting Parties to the CCW added consideration of how developments in the field of S&T relevant to the Convention may be addressed under the Convention to the agenda of the 2017 Meeting of States Parties (Final Document of the Fifth Review Conference, Un doc CCW/CONF.V/10, 23 December 2016, Section III, Decision 4). At that meeting, states parties decided against retaining that agenda item. Consideration of S&T is since then subsumed under the broader item of 'Emerging Issues in the context of the objectives and purposes of the Convention' (Meeting of the High Contracting Parties to the CCW, Consideration and adoption of the final report, UN doc CCW/MSP/2017/8, 11 December 2017, §37).

138 Reply from the United States of America, Report of the Secretary-General on current developments in science and technology, p. 43: 'the United States does not believe that a United Nations high-level panel of experts tasked with assessing current developments in science and technology and their potential impact on international security and disarmament efforts could achieve a useful outcome'; Reply from India, Report of the Secretary-General on current developments in science and technology, p. 25: 'there is no immediate need for new forums'; Reply from Japan, p. 27: 'it is also important to avoid launching new initiatives in duplication of existing or already-proposed ones'.

139 Report of the Secretary-General on current developments in science and technology, §2.

140 Jasanoff, *The Ethics of Invention*, p. 4.

141 Edwards, *Insecurity and Emerging Biotechnology,* p. 85.

142 L. Vinsel, 'Sorry, But We Can't Fantasize Our Way Out of This Mess', *Fast Company*, 10 June 2018, https://www.fastcompany.com/90247038/sorry-but-we-cant-fantasize-our-way-out-of-this-mess.

143 S. Poole, 'Wake up, Humanity! A Hi-Tech Dystopian Future is not Inevitable', *The Guardian*, 18 February 2019, https://www.theguardian.com/commentisfree/2019/feb/18/technological-progress-superjumbo-airbus-dystopia-future.

144 UNODA, *Securing Our Common Future*, p. 10.

145 Jasanoff, *'Technologies of Humility'*, 243.

146 Vinsel, 'Sorry, But We Can't Fantasize Our Way Out of This Mess'.

147 UNODA, *Securing Our Common Future*, p. 12.

148 R. A. W. Rhodes, 'Waves of Governance', D. Levi-Faur (ed.), *The Oxford Handbook of Governance*, 2012, Adobe Digital edn, p. 62. See also Jasanoff, *The Ethics of Invention*, p. 345: 'the political life of societies is itself a form of collective storytelling, a joint and several imagining of the purposes and the potential of living and working together on an Earth at once malleable and constraining'.

ANNEXES

ACOUSTIC WEAPONS

DISCUSSION PAPER FOR THE CONVENTION ON CERTAIN CONVENTIONAL WEAPONS (CCW)

GENEVA, NOVEMBER 2018*

Acoustic (or sonic) weapons are under research and development in a few countries and have been the subject of interest and much speculation for several decades.[1] Such devices have repeatedly captured the interest of the press, most recently when it was reported in 2016 that several staff members at the American embassy in Cuba were allegedly 'subjected to an "acoustic attack" using sonic devices' that caused serious health problems.[2] Neurologists and engineers have challenged this claim.[3]

Acoustic weapons aim to use the propagation of sound – a variation in pressure that travels through a fluid medium (such as air) to affect a target. Most of the acoustic weapons that have been speculated upon are based on either ultrasound (above 20 kilohertz, kHz), low frequencies (below 100 hertz, Hz) or infrasound (below 20 Hz) deployed at high levels.[4] The human range of hearing is commonly given as between 20 Hz and 20 kHz. In reality, the upper hearing-threshold frequency decreases significantly with age, whereas sounds with lower frequencies can be heard and otherwise perceived if the level is high enough.[5]

Although a few acoustic devices exist today that could be used as weapons, and sound is implicated in the use of force in the military and law enforcement domains in various ways, the potential for weaponization of acoustic devices has likely been overstated.[6] Recent scientific analyses have debunked myths and disproven earlier claims about the effects of acoustic devices on humans and have drawn attention to the practical limitations of such technologies.[7]

Nevertheless, consideration of acoustic weapons brings to the fore a number of issues that deserve attention from the perspective of multilateral weapons control, including within the framework of the Convention on Certain Conventional Weapons (CCW):

- Often branded as 'non-lethal' or 'less lethal',[8] acoustic devices are open to the same questions and criticisms levelled against other technologies given that label (including that they may undermine boundaries distinguishing acceptable modalities of force in war-fighting and in law enforcement, and that their use in conjunction with kinetic weapons actually increases the risk of death).
- Acoustic weapons raise questions of delineation between devices specifically designed to harm through

* The paper was updated on 3 December 2018 to note the position of Cuba in footnote 2.

acoustic phenomena like sound or vibration (acoustic weapons properly speaking), other weapons with harmful acoustic effects (such as explosive weapons) and the use of organized sound (music) or unorganized sound (noise) by militaries and police, including to torture or terrorize. Such delineation in turn has consequences for national and international control and raises further questions about the role of international regulation.

× Consideration of acoustic weapons raises the question of our orientation towards technologies that target the human senses ('sensory violence'). Parallels that could be drawn from the prohibition on blinding laser weapons (formalized in CCW Protocol IV) and the opprobrium attached to blinding as a method of warfare deserve further exploration in light of the evolving understanding of deafness and blindness from a health perspective.

× Consideration should be given to the ethical, health, legal and environmental concerns about the acceptability and desirability of acoustic violence – sound as a technique of authority and control[9] – especially in frequencies beyond the human audible range,[10] and the expansion of weaponized sound into civilian spheres. As with directed energy weapons, some acoustic weapons may raise questions about systems where the source of harm is not identifiable or comprehensible to those experiencing it.

× Given the well-documented health impacts of weapon noise on humans, consideration of acoustic devices also raises the question of whether political measures should be taken at the international level to better protect both civilians and soldiers from weapons that cause noise-induced hearing loss.

× Finally, there is concern that a lack of reliable, scientifically sound and peer-reviewed data on the specifications and effects of acoustic devices[11] has in the past driven research and development (including animal testing) into acoustic weapons in expectation of unrealistic potential. This has contributed to speculations and public anxiety about acoustic, especially infrasound, weapons.

CURRENT STATE OF PLAY

The fascination that acoustic weapons prompt among certain militaries, police forces, journalists, scientists and publics has to be understood against the backdrop of a complex and long-standing relationship between sound, war and violence.[12] What accounts of such diverse phenomena as the Nazi-German 'Windkanone', Soviet 'psychocorrection methods', the US 'Urban Funk Campaign', the British 'Curdler' and the use of sound to torture,[13] harass, intimidate or terrorize[14] have in common is a long-standing belief (justified or not) in the destructive power of sound and vibration. This belief and the search for bloodless, so-called 'non-lethal' technologies of violence, which intensified from the early 1990s, have driven some states, mainly the US, to push research and development into acoustic weapons, especially in the infra- and ultrasonic frequency ranges.

Decades of research and development and considerable hype notwithstanding, the potential for weaponization of acoustic devices has likely been overstated.[15] Inherent difficulties in projecting sound energy to tactical ranges, as well as limited human effects in practice,[16] have hampered the attempts of states and scientists to produce an acoustic-based weapon that can be fully operationalized. Low frequency and infrasound can travel over considerably larger distances than higher-frequency sound and are hardly attenuated through dissipation.[17] However, at low frequency, sound cannot be projected in a directed beam; at higher frequency, it can. But if high-frequency sound waves are to have an impact on humans, the sound pressure would need to reach such a level that the sound waves become deformed.[18] In order to produce such effects, the sound source with its auxiliary equipment would be of a weight and dimension that could not easily be carried by a single person, limiting practical military and law enforcement applications.[19]

Certain types of acoustic devices currently reported to be in use by law enforcement or military actors have drawn particular attention – and criticism – and raise questions that are of interest from the perspective of multilateral weapons control more broadly. These include acoustic hailing devices, flash-bang devices, and high-frequency devices, all briefly described below.

Acoustic hailing devices (AHD) or 'sound cannons'

AHD operate in the audible range and issue high-energy acoustic beams to communicate with, warn and potentially disorient or disable a person. A number of states have developed and are using such systems,[20] in both military and law enforcement settings, primarily in connection with crowd and border control. Such devices can reportedly produce 'harmful, pain-inducing tones' over some distance,[21] and can damage the human ear and even cause permanent hearing loss over short distances.

The best-known of these devices is the Long Range Acoustic Device (LRAD). It resembles a flat loudspeaker that uses many piezoelectric transducers, set in a staggered arrangement.[22] The LRAD was developed as a military tool to enforce exclusion zones around naval vessels following an attack on the navy warship USS Cole in Yemen in 2000. It has subsequently been used by the US navy to protect shipping lanes around the Iraqi port of Basra and nearby oil terminals.[23] It has also reportedly been used for 'hailing and warning' by cruise and transport liners to deter pirates,[24] been deployed by police forces in several countries[25] and is being attached to drones.[26]

The LRAD has relatively high directivity (with a beam opening angle of 5–15 degrees) and transmits mainly high frequencies (above 1 kHz). The LRAD 1000 projects voice messages to a range above 500 m, and warning tones to above 1000 m.[27] Various, scaled-down and scaled-up versions are available.[28]

There are also reports that similar devices, termed 'sonic blasters', have been used to produce a series of high-intensity blasts (high levels of sound pressure and volume) to affect a target rather than to communicate. Among the most reported examples are Israel's sonic pulser, 'The Scream',[29] and its 'Thunder Generator', originally developed as 'an environmentally friendly soil-disinfection machine' to scare away birds from crops, and later used for riot control.[30]

Flash-bang devices

Flash-bang devices (or 'noise flash diversionary devices') contain mixtures of fast-burning propellants and pyrotechnics to produce a loud 'bang' and a bright flash of light. They often take the form of grenades ('stun grenades', 'flash-bang grenades', 'sound bombs') that are deployed by hand or from shotgun cartridges.[31]

Flash-bang grenades are in widespread use by military and law enforcement actors and are designed to temporarily blind, disorient and cause dizziness. As the casing is not intended to produce fragmentation during detonation, such flash-bang devices are typically labelled 'non-lethal'. There are, however, several known cases of serious injury and death resulting from their use.[32]

A US performance characterization study of selected flash-bang devices noted that one of the concerns associated with their use 'is the high level of sound generated by them, with respect to hearing impairment or damage'.[33] All of the devices tested in the study exceeded the US Department of Defense's 140 decibel (dB) threshold requirement for use of hearing protection. According to one source, the 'threshold noise' of a flash-bang device 'can reach 180 dB in closed spaces, where the effects of the acoustic signature can be compounded'.[34] This is comparable to the peak levels of heavy artillery (measured at the shooter's position close to the gun).[35]

High-frequency devices

The particularity of high-frequency devices is that they emit a sound at a frequency on the border of being ultrasonic, which is intended to be heard only by younger people, whose ears tend to be more sensitive to sound at high frequency compared to most older people.

The best-known model is the 'Mosquito Teenager Deterrent/Anti-Loitering Device'. This was initially developed to disperse vermin and is now primarily marketed to private persons and businesses 'for dispersing groups of misbehaving teenagers'.[36] According to the manufacturer, the Mosquito MK4 can be set to emit a sound at 17 kHz that only people under 25 can hear or at 8 kHz, audible to people of any age, with four volume/distance settings and a maximum volume of 103 dB.[37]

ADVERSE EFFECTS AND RISKS

Acoustic devices can produce a range of harmful effects, most notably temporary and permanent hearing loss, as well as pain, disorientation, sensations of discomfort and nausea.[38] Importantly, the physiological and psychological effects of sound on humans depend not only on frequency, but also on sound pressure levels, duration and number of exposures and recovery time between exposures.[39] And, effects vary significantly from one individual to another.

At 120 dB, where discomfort typically begins, there is a high risk of hearing loss even for short and few exposures. Lasting damage to the ear can occur at levels below the threshold for ear pain, which sets in at between 135 and 162 dB depending on frequency.[40] At extreme levels, physical damage to organs of the ear can occur even with short exposure.[41] At about 160 dB, sound in the audio region causes eardrum rupture. Infrasound at high levels can produce aural pain and damage, a sensation of pressure in the middle ear and annoyance, but it does not have the profound effects often associated with it.[42] Ultrasound at extreme levels (close to 160 dB) was reported to produce a slight heating effect that could be felt on the skin.[43]

As with other technologies labelled 'non-lethal', the use of acoustic devices has attracted strong criticisms from humanitarian, health and human rights perspectives. In a war-fighting context, concern has been raised that when an acoustic device is 'used in a pre-lethal way to incapacitate before killing' it actually increases the 'killing power of lethal force' rather than reducing casualties.[44] Critics also object to the extension of weaponized sound to (domestic) law enforcement and the associated blurring of the boundaries of acceptable ways of applying force. In a number of concrete situations, users were considered to have taken insufficient care to protect the lives and health of people within the range of acoustic devices, and to account for the specifics of a situation and individual differences in susceptibility to injury and trauma.[45]

More generally, critics complain of a lack of proper documentation regarding effects at various frequencies and levels in actual-use situations, as well as a lack of analyses by independent bodies. This is not only a humanitarian concern, but it also challenges democratic control over the use of force and enables misconceptions and speculations to endure about the effects of acoustic devices, justifying the allocation of funds for further research and development, with potentially negative consequences for international and human security.

GOVERNANCE AND REGULATION

'Acoustic weapons' or 'acoustic devices' are not authoritatively defined or regulated in international law, nor are they the subject of dedicated multilateral policy discussions.[46] The potential to use acoustic devices to communicate or warn, as well as to compel, intimidate or injure, for domestic law enforcement and military purposes (as well as by private citizens), has sparked debate in legal quarters about how such devices, in particular the LRAD, should be properly categorized. Some argue that they are hailing devices that should neither be subject to national weapons reviews, including those warranted by Article 36 of 1977 Additional Protocol I,[47] nor to export controls applicable to weapons.[48] Others have taken the opposite view.[49] A NATO study, for instance, describes 'acoustic devices' as '[w]eapons utilizing acoustic energy to induce human effects through the sense of hearing or through the direct impact of pressure waves on other parts of the human body'.[50]

The question of categorization aside, a number of existing regulatory frameworks constrain the use of sound in connection with the use of force, notably international humanitarian law (IHL) and international human rights law (IHRL), as well as national health and safety standards. In relation to the conduct of hostilities, the question is often asked whether the use of acoustic devices would comply with the IHL prohibition on the use of weapons and methods of warfare of a nature to cause superfluous injury or unnecessary suffering.[51] The US, for example, has determined that the LRAD does not violate that legal threshold, 'because the discomfort is well short of permanent damage to the ear'.[52] An earlier preliminary assessment by the US Navy had concluded that even 'aural systems that could cause permanent hearing loss' would not be illegal.[53] At the international level, the debate is complicated by divergent interpretations of the rule on superfluous injury and continued disagreement about the (il-)legality of blinding (and thus, by analogy, deafening) as a method of warfare.

In this connection, it is sometimes proposed that a prohibition on acoustic weapons could be derived, by analogy, from the prohibition on blinding laser weapons,[54] another 'non-lethal' technology that targets the human senses. This argument has been rejected on the grounds that 'the eye provides 90% of sensory input, the ear accordingly provides much less. Moreover, permanent hearing loss is not necessarily complete loss and prolonged hearing loss means that such loss is only temporary'.[55] Such a statement betrays a common bias that ranks vision over other senses (ocularcentrism)[56] and fails to take account of evolving understandings of deafness (and blindness) from medical and public health perspectives. It also speaks to a lack of in-depth and critical consideration of sound and the 'acoustic authority' of the state (the 'politics of frequency and amplitude')[57] in contemporary legal thought.[58]

Legal commentators have further pointed to the great potential for indiscriminate effects from the use of acoustic devices, which may violate the IHL rule on distinction and the prohibition of indiscriminate attacks.[59] Testing has shown that the LRAD, for example, does not only affect those targeted by the device but also bystanders in the directional periphery.[60] Especially at longer ranges, questions arise regarding the controllability of the propagation of sound, as 'the transmission direction will be deflected in case of strong winds'[61] or reflected off surfaces in built-up environments.[62]

The 'indiscriminateness' of acoustic devices is also a major human rights concern. Pertinent international standards on the use of force in law enforcement operations require that 'the development and deployment of non-lethal incapacitating weapons should be carefully evaluated in order to minimize the risk of endangering uninvolved persons, and the use of such weapons should be carefully controlled.'[63] In several cases, legal challenges have been brought over injuries caused by the use of flash-bang devices in law enforcement situations[64] – use that raises questions concerning the rights to life or health, and freedom of peaceful assembly and movement where the devices were used for crowd control.[65]

Moreover, acoustic devices that target the hearing of a group of people on the basis of their age, as does the Mosquito, raise issues regarding the right to equality and non-discrimination and from a child rights perspective.[66] The device has been declared illegal in some jurisdictions.[67] Devices that are inaudible (to adults) also raise a rule of law concern as affected populations may face formidable challenges in accessing an effective remedy.[68] Finally, it bears restating that both IHL and IHRL prohibit the use of sound and acoustic devices to terrorize, torture or inflict inhuman or degrading treatment.[69]

In terms of governance and regulation, acoustic devices raise the question of what constitutes an acceptable health risk and what the standard of reference should be given their diverse applications in military, law enforcement and private settings. In the military, where noise exposure is a well-known problem, a number of impulse-noise exposure criteria have been developed.[70] 'Safe exposure' to *impulse* noise is sometimes given as a peak level of 162 dB,[71] but a 2003 NATO research study was unable to propose a single measure or assessment method to predict the auditory hazard for different impulse noises and blasts.[72]

In relation to *continuous* sound, the World Health Organization considers that exposure levels above 85 dB in an occupational setting are 'hazardous for workers',[73] and deems exposure to recreational sound in excess of 85 dB for eight hours or 100 dB for 15 minutes 'unsafe'.[74] Although these standards aim to protect workers from damage over years of exposure, in a Canadian case implicating an LRAD, the judge considered that occupational health and safety legislation served as a useful guide to determine restrictions on the use of LRAD to prevent unsafe exposure which would amount to human rights violations.[75] In 2011, Canadian authorities defined minimum distances at various levels for 'urban scenarios', and recommended that the use of the alert function (i.e. use to emit a high-decibel, narrow-frequency sound wave rather than use as a powerful loudspeaker) 'should be minimized', that the devices 'should not be operated continuously' and that any use should be followed by an equivalent period of silence.[76]

In the same vein, Jürgen Altmann has proposed rules for safe operation to prevent injury. He suggests technical measures to limit the sound power of LRAD as a function of distance between the device and the exposed population, and to limit the duration of use, as well as a ban on particular types (such as certain mobile LRAD) and a requirement to document any use of a device automatically.[77] Taking a precautionary orientation, Amnesty International and Omega Research Foundation recommend that the use of acoustic devices in the alert function be suspended 'until an independent body of medical, scientific, legal and other experts has subjected the effects and potential uses of the type of device in question to rigorous assessment and can then demonstrate a legitimate and safe use of the device for law enforcement subject to specific operational rules consistent with human rights standards.'[78]

Measures on acoustic weapons at the national and international levels can build on a rich literature on non-lethal weapons in the use of force, including detailed recommendations on selection, testing, deployment, operational procedures, training, monitoring and accountability, for multilateral controls as well as specific legal instruments.[79]

NOTES

1 See, e.g., N. Broner, 'The Effects of Low Frequency Noise on People – A Review', 58(4) *Journal of Sound and Vibration* (1978), https://waubrafoundation.org.au/resources/broner-n-effects-low-frequency-noise-people-review/. The work of Vladimir Gavreau is often cited in this context (see, e.g., G. Vassilatos, 'The Sonic Doom of Vladimir Gavreau', 52(4) *Borderlands* (1996), https://borderlandsciences.org/journal/vol/52/n04/Vassilatos_on_Vladimir_Gavreau.html). His work has more recently been described as 'unscientific' (J. H. Mühlhans, 'Low Frequency and Infrasound: A Critical Review of the Myths, Misbeliefs and Their Relevance to Music Perception Research', 21(3) *Musicae Scientiae* (September 2017) 272).

2 E. Labott et al, 'US Embassy Employees in Cuba Possibly Subject to "Acoustic Attack"', CNN, 10 August 2017, https://edition.cnn.com/2017/08/09/politics/us-cuba-acoustic-attack-embassy/index.html. Cuba has denied any involvement, see E. McKirdy et al, 'Cuban president denies "sonic" attacks on US diplomats', CNN, 17 September 2018, https://edition.cnn.com/2018/09/17/americas/cuba-sonic-attack-miguel-diaz-canal-denial-intl/index.html.

3 E.g. R. E. Bartholomew, 'Politics, Scapegoating and Mass Psychogenic Illness: Claims of an "Acoustical Attack" in Cuba are Unsound', 110(12) *Journal of the Royal Society of Medicine* (2017); C. C. Muth and S. L. Lewis, 'Neurological Symptoms Among US Diplomats in Cuba', 319(11) JAMA (20 March 2018). Researchers who reverse-engineered a recording of what embassy staff heard concluded, however, that '[i]f ultra-sound is to blame, then a likely cause was two ultra-sonic signals that accidentally interfered with each other, creating an audible side effect' (J. Kumagai, 'Reverse Engineering the "Sonic Weapon"', 55(3) *IEEE Spectrum* (March 2018), https://ieeexplore.ieee.org/abstract/document/8302371). See also I. Sample, 'Cuban "Acoustic Attack" Report on US Diplomats Flawed, Say Neurologists', *The Guardian*, 14 August 2018, https://www.theguardian.com/world/2018/aug/14/cuban-acoustic-attack-report-on-us-diplomats-flawed-say-neurologists.

4 N. Davison, *'Non-Lethal' Weapons*, Palgrave Macmillan, 2009, p. 186.

5 J. Altmann, 'Acoustic Weapons – A Prospective Assessment', 9(3) *Science & Global Security* (2001) 173, scienceandglobalsecurity.org/archive/sgs09altmann.pdf; Mühlhans, 'Low Frequency and Infrasound', 270.

6 A NATO study notes: 'A large variety of acoustic devices have been proposed for non-lethal applications. Most are of uncertain effectiveness and many could damage hearing.' (North Atlantic Treaty Organization, *The Human Effects of Non-Lethal Technologies*, RTO Technical Report, NATO doc AC/323(HFM-073)TP/65, August 2006, p. G-4, https://www.sto.nato.int/publications/STO%20Technical%20Reports/RTO-TR-HFM-073/$$TR-HFM-073-ALL.pdf.). See also J. R. Jauchem and M. C. Cook, 'High-Intensity Acoustics for Military Nonlethal Applications: A Lack of Useful Systems', 172(2) *Military Medicine* (2007) 186, https://academic.oup.com/milmed/article/172/2/182/4578046.

7 See in particular Altmann, 'Acoustic Weapons'; Mühlhans, 'Low Frequency and Infrasound'.

8 See in particular D. P. Fidler, 'The Meaning of Moscow: "Non-Lethal" Weapons and International Law in the Early 21st Century', 87(859) *International Review of the Red Cross* (September 2005), https://www.icrc.org/eng/assets/files/other/irrc_859_fidler.pdf; N. Lewer and N. Davison, *Bradford Non-Lethal Weapons Research Project* (BNLWRP), *Research Report no. 7*, May 2005, https://bradscholars.brad.ac.uk/handle/10454/3999.

9 J. E. K. Parker, 'Towards an Acoustic Jurisprudence: Law and the Long Range Acoustic Device', 14(2) *Law, Culture and the Humanities* (2018) 209.

10 Steve Goodman speaks of a 'creeping colonization of the not yet audible and the infra- and ultrasonic dimensions of unsound' (S. Goodman, *Sonic Warfare: Sound, Affect, and the Ecology of Fear*, The MIT Press, 2010, p. xvi) and Juliette Volcler cites SPIRAW's 'recherche des frontières que colonisent tranquillement les militaires et les forces de police à travers l'usage d'armes soniques' (J. Volcler, 'Le son comme arme', *Article XI*, February 2010, revised January 2011, https://www.article11.info/spip/IMG/pdf/v2_le_son_comme_arme.pdf).

11 Most of the information about such devices comes from the US, which has publicly reported more on its research and development in this area than most other states.

12 For an in-depth treatment of this issue, see Goodman, *Sonic Warfare*; J. M. Daughtry, *Listening to War: Sound, Music, Trauma, and Survival in Wartime Iraq*, Oxford University Press, 2015; N. Ramsey, 'Listening to War: Sound and Noise in Romantic Era Military Writing', 5(2) *Republics of Letters* (2017), https://arcade.stanford.edu/sites/default/files/article_pdfs/RofL_v06i01_Ramsey_03Pass.pdf.

13 See in particular S. G. Cusick, 'Music as Torture / Music as Weapon', *Revista Transcultural de Música* (2006), https://www.sibetrans.com/trans/articulo/152/music-as-torture-music-as-weapon.

14 Well-documented instances include American troops blasting the Vatican's embassy in Panama City to dislodge Noriega in 1990 (A. Campoy, 'The US Pursuit of Panama's Manuel Noriega Kicked Off a New Era of Music Torture', *Quartz*, 30 May 2017, https://qz.com/994372/manuel-noriegas-capture-in-panama-kicked-off-a-new-era-of-sound-as-psychological-warfare/); the FBI's sonic assault in Waco in 1993 (V. Madsen, '*Cantata of Fire: Son et Lumière* in Waco Texas, Auscultation for a Shadow Play', 14(1) *Organized Sound* (2009)); the sonic booms of Israeli fighter jets flying at low altitude over Palestinian cities in 2005 (C. McGreal, 'Palestinians Hit by Sonic Boom Air Raids', *The Guardian*, 3 November 2005, https://www.theguardian.com/world/2005/nov/03/israel); US jets over Nicaraguan cities in 1984 (International Court of Justice, *Military and Paramilitary Activities in and Against Nicaragua* (*Nicaragua v United States of America*), Judgment (Merits), 27 June 1986, §§87, 91) and the blasting of music during the US siege of Falluja in 2004 (J. Pieslak, *Sound Targets: American Soldiers and Music in the Iraq War*, Indiana University Press, 2009, p. 84). For more information on these phenomena, see Volcler, 'Le son comme arme'; Cusick, 'Music as Torture / Music as Weapon', Daughtry, *Listening to War*; Goodman, *Sonic Warfare*.

15 Davison, *'Non-Lethal' Weapons*, p. 186.

16 See J. Altmann, *Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons? Physics Analyses and Inferences*, Deutsche Stiftung Friedensforschung, 2008, p. 44, https://www.ssoar.info/ssoar/handle/document/26039 (noting that 'after almost ten years of research, the [US Joint Non-Lethal Weapons Program] stopped funding infrasound-weapon work for lack of "a reliable, repeatable bio-effect with sufficiently high infrasound amplitude at a minimum specified range"') and Jauchem and Cook, 'High-Intensity Acoustics for Military Nonlethal Applications', 186 (concluding that '[o]n the basis of results of numerous investigators, it seems unlikely that high-intensity acoustic energy in the audible, infrasonic, or low-frequency ranges will provide a device suitable to be used as a nonlethal weapon').

17 Mühlhans, 'Low Frequency and Infrasound', 269.

18 Altmann, 'Acoustic Weapons', 165.

19 The size and mass differ between infra- and ultrasound devices, but hand-held acoustic weapons of pistol or rifle sizes with a range of tens of metres are highly unlikely according to Altmann (Ibid., 199–200, 204).

20 Altmann, *Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons?*, p. 6.

21 E. Durr, 'Training with High-Tech Hailer System on the Hudson', *Guard Times* (Spring 2015), 43, https://issuu.com/nynationalguard/docs/gt_spring_15_1_.

22 N. Lewer and N. Davison, 'Non-Lethal Technologies – An Overview', 1 *Disarmament Forum* (2005) 41, https://www.peacepalacelibrary.nl/ebooks/files/UNIDIR_pdf-art2217.pdf.

23 Business Wire, 'American Technology Reports on Growing Long Range Acoustic Devices – LRAD – Business', 26 August 2004, https://www.businesswire.com/news/home/20040826005135/en/American-Technology-Reports-Growing-Long-Range-Acoustic. Its precursors were, however, initially envisaged for civilian markets, unrelated to the use of force. For more information, see Parker, 'Towards an Acoustic Jurisprudence', 210–211.

24 A. Blenford, 'Cruise Lines Turn to Sonic Weapon', *BBC News*, 8 November 2005, http://news.bbc.co.uk/2/hi/africa/4418748.stm.

25 See, e.g., ACLU Pennsylvania, 'City of Pittsburgh Settles G-20 Lawsuits', 14 November 2012.

26 Parker, 'Towards an Acoustic Jurisprudence', 214, https://www.aclupa.org/news/2012/11/14/city-pittsburgh-settles-g-20-lawsuits.

27 Altmann, *Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons?*, p. 6.

28 See the manufacturer's website: https://www.lradx.com/products/.

29 Y. Katz, 'Kalandiya: IDF Uses "Scream" Anti-Riot Device for 1st Time', *Jerusalem Post*, 22 September 2011, www.jpost.com/Defense/Kalandiya-IDF-uses-Scream-anti-riot-device-for-1st-time.

30 PDT Agro Ltd 'Bird Control Solution', http://pdtagro.com/; D. Hambling, 'A Sonic Blaster So Loud, It Could Be Deadly', *Wired*, 18 January 2010, https://www.wired.com/2010/01/a-sonic-blaster-so-loud-it-could-be-deadly/#more-21519.

31 E.g. Amtech Less Lethal Systems, 'ALS1208 Bore Thunder Muzzle Bang', https://www.lesslethal.com/products/12-gauge/als1208-detail; Defense Technology, '12-Gauge Aerial Warning / Signaling Munition, 100 Meters', http://www.defense-technology.com/products-1/12-gauge-aerial-warning-signaling-munition-100-meters-1154107.html#start=1.

32 For example, in 2014, a French protester died after being hit in the back by a stun grenade ('Sivens: des traces d'explosifs retrouvés sur les vêtements de Rémi Fraisse', *L'OBS*, 28 October 2014, https://www.nouvelobs.com/societe/20141028.OBS3407/sivens-des-traces-d-explosifs-retrouves-sur-les-vetements-de-remi-fraisse.html). The use of these grenades was suspended shortly after the incident, and then prohibited in 2017 ('Plus de deux ans après la mort de Rémi Fraisse, les grenades offensives de type F1 interdites', *Le Monde/AFP*, 12 May 2017, https://www.lemonde.fr/police-justice/article/2017/05/12/plus-de-deux-ans-apres-la-mort-de-remi-fraisse-les-grenades-offensives-de-type-f1-interdites_5126979_1653578.html). See also J. Angwin and A. Nehring, 'Hotter Than Lava', *ProPublica*, 12 January 2015, https://www.propublica.org/article/flashbangs; J. Volcler, *Extremely Loud: Sound as a Weapon*, The New Press, 2013, pp. 59–61.

33 E-LABS Inc., Performance Characterization Study: Noise Flash Diversionary Devices (NFDDs), Final Report, December 2003, p. 5, https://www.ncjrs.gov/pdffiles1/nij/grants/205642.pdf.

34 D. Whitson and J. Clark, 'Flash/Sound Diversionary Devices: A Comprehensive Review', *The Tactical Edge* (Summer 2011) 18, https://www.combinedsystems.com/userfiles/pdfs/Whitson_SU_2011_1.pdf. See also W. A. Burgei et al, 'Developing Non-Lethal Weapons: The Human Effects Characterisation Process', *Defense AT&L* (May-June 2015) 30-34, www.dtic.mil/dtic/tr/fulltext/u2/1015792.pdf.

35 E.g. A. Nakashima and R. Farinaccio, 'Review of Weapon Noise Measurement and Damage Risk Criteria: Considerations for Auditory Protection and Performance', 180(4) *Military Medicine* (2015) 402.

36 Compound Security Systems, 'Anti-Loitering Devices', https://www.compoundsecurity.co.uk/security-equipment/mosquito-mk4-anti-loitering-device.

37 Compound Security Systems, 'Mosquito MK4 (Anti-Loitering Device): Customise Your Own Kit', https://www.compoundsecurity.co.uk/security-equipment-mosquito-mk4-anti-loitering-device.

38 For a recent study on physical and psychological effects of sound, see J. P. Cowan, *The Effects of Sound on People*, Wiley, 2016.

39 Davison, 'Non-Lethal' Weapons, p. 186. Mühlhans notes that in relation to low frequency, including infrasound, 'the effects depend [...] heavily on sound-pressure levels and considerably less on frequency or the nature of sound.' (Mühlhans, 'Low Frequency and Infrasound', 268).

40 Altmann, 'Acoustic Weapons', 177.

41 Ibid., 174.

42 Davison, *'Non-Lethal' Weapons*, p. 186. See also Mühlhans, 'Low Frequency and Infrasound', debunking several myths about infrasound.

43 Altmann, 'Acoustic Weapons', 186.

44 Davison, *Bradford Non-Lethal Weapons Research Project* (BNLWRP), *Research Report no. 7*, p. 34.

45 For example, during the FBI's Waco siege, it exposed 25 children, many of them toddlers and infants, to the same sound campaign as adults. See, e.g., A. A. Stone et al, 'Report and Recommendations Concerning the Handling of Incidents Such as the Branch Davidian Standoff in Waco Texas', Submission to Deputy Attorney General Philip Heymann, 10 November 1993, Frontline, Waco: The Inside Story, https://www.pbs.org/wgbh/pages/frontline/waco/stonerpt.html.

46 Consider, however, Working Paper COLU/202 on fuel-air explosives, submitted by Sweden in the 1970s, which proposed to prohibit 'the anti-personnel use of weapons which for their effects rely exclusively on shock waves in the air'. When confronted with the criticism that this formulation would capture weapons other than fuel-air explosives, 'e.g. concussion grenades', the sponsor of the proposal responded that 'there were advantages in the use of forward-looking wording' (ICRC, *Conference of Government Experts on the Use of Certain Conventional Weapons (Second Session – Lugano 28.1.-26.2.1976)*, Report, Geneva, 1976, §75).

47 See, e.g., J. Schrantz, 'The Long Range Acoustic Device: Don't Call It a Weapon – Them's Fightin' Words', *Army Lawyer* (August 2010) 53–59, https://www.loc.gov/rr/frd/Military_Law/AL-2010.html; LRAD, 'Fact Sheet', https://www.lradx.com/about/lrad-public-safety-applications-fact-sheet/.

48 The US LRAD was reportedly exported to China (D. Hambling, 'US "Sonic Blasters" Sold to China', *Wired*, 15 May 2008, https://www.wired.com/2008/05/us-sonic-blaste/). On export control questions, see also Omega Research Foundation and Amnesty International USA, *Submission in Response to BIS Request for Public Comments on Crime Control License Requirements in EAR*, 17 June 2008, pp. 7–8, https://omegaresearchfoundation.org/sites/default/files/uploads/Publications/090000648062f0f5.pdf.

49 Altmann, citing R. Sævik, notes that the Norwegian military call it a weapon (Altmann, *Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons?*, p. 44). Consider also a recent US ruling finding that the New York City Police Department use of an LRAD for crowd control in 2014 constituted 'excessive force' (United States Court of Appeals for the Second Circuit, *Edrei v Bratton*, Docket no. 17-2065, 13 June 2018). Similarly, under the Irish 1997 Non-Fatal Offences Against the Person Act, the definition of 'force' in relation to the offence of assault includes the application of 'noise' (Art 2(2)).

50 NATO, *The Human Effects of Non-Lethal Technologies*, p. G-4.

51 Art 35(2), 1977 Additional Protocol I (API) to the Geneva Conventions; ICRC Customary IHL Study, Rule 70.

52 Schrantz, 'The Long Range Acoustic Device', 58, citing a US Army legal review memorandum of 2007, at which time several hundred LRAD had already been deployed.

53 J. P. Winthrop, *Preliminary Legal Review of Proposed Acoustic Energy Non-Lethal Weapon Systems*, Department of the Navy, Office of the Judge Advocate General, 29 April 1998, pp. 8–9.

54 1995 Protocol on Blinding Laser Weapons (Protocol IV to the Convention on Certain Conventional Weapons); ICRC Customary IHL Study, Rule 86.

55 S. Casey-Maslen, *Non-Kinetic-Energy Weapons Termed 'Non-Lethal': A Preliminary Assessment Under International Humanitarian Law and International Human Rights Law*, Geneva Academy of International Humanitarian Law and Human Rights, October 2010, https://www.geneva-academy.ch/joomlatools-files/docman-files/Non-Kinetic-Energy%20Weapons.pdf; Altmann, 'Acoustic Weapons', 206.

56 Goodman, *Sonic Warfare*, p. 9. Parker reminds us that '[s]ound is experienced by the entire body' and 'is profoundly haptic' (Parker, 'Towards an Acoustic Jurisprudence', 203).

57 Goodman recognizes 'a tension between two critical tendencies tagged the politics of noise and the politics of silence' that constitute 'the typical limits to a politicized discussion of the sonic' (Goodman, *Sonic Warfare*, pp. 17–20). Parker notes that '[t]he LRAD's sheer volume means that, irrespective of what is being said, it will likely register affectively as a threat' (Parker, 'Towards an Acoustic Jurisprudence', 216).

58 Parker, 'Towards an Acoustic Jurisprudence', 206.

59 Art 51(4), API; ICRC Customary IHL Study, Rules 11 and 12.

60 A. Dymond-Bass and N. Corney, 'The Use of "Less-Lethal" Weapons in Law Enforcement', S. Casey-Maslen (ed.), *Weapons and International Human Rights Law*, Cambridge University Press, 2014, p. 42.

61 Altmann, *Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons?*, p. 49. See also W. M. Arkin, 'Acoustic Anti-Personnel Weapons: An Inhumane Future?', 13(4) *Medicine, Conflict and Survival* (2007) 320.

62 A Canadian review of the LRAD100X and the LRAD300X notes that 'within a city setting the sound levels of the LRAD could be 3 to 6 dB higher than in an open air environment' (Ministry of Community Safety and Correctional Services, *Review of Police Use of Long-Range Acoustic Devices*, p. 12, www.acoustical-consultants.com/wp-content/uploads/2012/03/LRAD-Report.pdf).

63 Art 3, 1990 UN Basic Principles on the Use of Force and Firearms by Law Enforcement Officials (BPUFF). Amnesty International has proposed guidelines for the implementation of the BPUFF with specific recommendations regarding non-lethal weapons testing and deployment and their use in crowd control (Amnesty International, *Use of Force: Guidelines for Implementation of the UN Basic Principles on the Use of Force and Firearms by Law Enforcement Officials*, 2015, Chapters 6 and 7, https://www.amnestyusa.org/reports/use-of-force-guidelines-for-implementation-of-the-un-basic-principles-on-the-use-of-force-and-firearms-by-law-enforcement-officials/.)

64 In particular, flash-bang devices have attracted severe criticism and legal challenges due to their capacity to cause severe injury and death. See, e.g., Angwin and Nehring, 'Hotter Than Lava'. On the right to health and non-lethal weapons generally, see E. Hoffberger, 'Non-Lethal Weapons: The Principle of Proportionality in Armed Conflict and the Right to Health in Law Enforcement', 38(2) *Zb. Prav. fak. Sveuč. Rij*. (2017) 844–847.

65 See, e.g., United States District Court for the Western District of Pennsylvania, *Karen L. Piper v. City of Pittsburgh et al*, Complaint, 21 September 2011. The case involved an LRAD and was settled. See also *Edrei v Bratton*, ruling that the New York City Police Department's use of an LRAD for crowd control in 2014 constituted 'excessive force'.

66 A German study warns that babies and young children are at particular risk of being exposed to the device for dangerously long periods because the adults accompanying them may not hear the sound and, thus, may not be able to protect them (German Federal Institute for Occupational Safety and Health, *Einsatz von Ultraschall-Störgeräusch-Sendern nicht ganz unbedenklich*, 14 December 2007, https://www.gesundheit-adhoc.de/einsatz-von-ultraschall-stoergeraeusch-sendern-nicht-ganz-un.html).

67 The French Tribunal de Grande Instance de Saint-Brieuc characterized it as an illegal sonic weapon (une 'arme sonore illicite'). See 'Le boîtier "antijeunes" interdit par la justice', *Le Monde*, 30 April 2008, https://www.lemonde.fr/societe/article/2008/04/30/le-boitier-antijeunes-interdit-par-la-justice_1040040_3224.html. For more detail, see Volcler, 'Le son comme arme'.

68 Volcler relates a 'Kafkaesque exchange' between people complaining about discomfort caused by a Mosquito illegally installed by a bank in Ixelles, Belgium, and police officers who can't hear anything and don't believe them (Volcler, 'Le son comme arme').

69 On 'subjection to noise' as a form of inhuman or degrading treatment, see, e.g., European Court of Human Rights, *Ireland v The United Kingdom*, App no. 5310/71, Judgment, 18 January 1978. (On 20 March 2018, the Court dismissed (pending request for referral to the Grand Chamber) an Irish request for revision of the judgment to the effect that the use of 'the five techniques of interrogation' amounted to torture, not merely inhuman and degrading treatment.) For a discussion of sound as torture, see Cusick, 'Music as Torture / Music as Weapon'.

70 See, e.g., G. Kerry and J. J. Bugge, *The NATO CCMS Working Group on Noise from Weapons – An Overview*, inter.noise 2000, 29th International Congress and Exhibition on Noise Control Engineering, 27–30 August 2000, Nice, France, www.conforg.fr/internoise2000/cdrom/data/articles/000842.pdf.

71 Altmann, 'Acoustic Weapons', 189.

72 NATO, *Reconsideration of the Effects of Impulse Noise*, RTO Technical Report TR-017, NATO doc AC/323(HFM-022)TP/17, April 2003, citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.214.6990&rep=rep1&type=pdf; Nakashima and Farinaccio, 'Review of Weapon Noise Measurement and Damage Risk Criteria', 404.

73 World Health Organization, 'Work-Related Noise', *The World Health Report* 2013, Chapter 4, http://www.who.int/whr/2002/chapter4/en/index8.html.

74 World Health Organization, '1.1 Billion People at Risk of Hearing Loss', Press Release, http://www.who.int/mediacentre/news/releases/2015/ear-care/en/.

75 See Parker, 'Towards an Acoustic Jurisprudence', 213–214.

76 The distance limits represent 'distances at which a sound level of 100 dBA [A-weighted decibels] would not be expected to be exceeded under the worst case conditions (full volume control setting, reflective ground surface, receptor located on the axis of the device at a location near a building) in the urban scenarios. Fifteen minutes of unprotected continuous exposure to 100 dBA corresponds to an equivalent sound exposure level over 8 hours [...] of 85 dBA.' (Ministry of Community Safety and Correctional Services, *Review of Police Use of Long-Range Acoustic Devices*, pp. 16–17).

77 Altmann, *Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons?*, p. 52. According to Altmann, to prevent permanent hearing damage from an LRAD, 'the warning tone must not be used closer than 5 m. The exposure duration has to be kept at a few seconds out to 50 m. Time limitations are needed to more than 100 m distance.' (p. 50)

78 Amnesty International and Omega Research Foundation, *The Human Rights Impact of Less Lethal Weapons and Other Law Enforcement Equipment*, 2015, p. 25, https://omegaresearchfoundation.org/publications/human-rights-impact-law-enforcement-equipment-april-2015.

79 N. Corney, *Less Lethal Systems and the Appropriate use of Force, Omega Research Foundation,* 2011, https://omegaresearchfoundation.org/sites/default/files/uploads/Publications/Less%20Lethal%20Systems%2C%20Corney%2C%202011.pdf; Amnesty International, *Use of Force*.

DIRECTED ENERGY WEAPONS

DISCUSSION PAPER FOR THE CONVENTION ON CERTAIN CONVENTIONAL WEAPONS (CCW)

GENEVA, NOVEMBER 2017

Directed Energy Weapons (DEW) have long captured military attention – and budgets – and are now on the cusp of technological maturity. Whilst doubts remain over whether certain types can be fully operationalized, recent tests of prototype DEW have made it clear that this form of weaponry has moved beyond just a theoretical concept. As the underlying technology matures and is subjected to testing outside of laboratories, it will likely attract increased attention from militaries and governments seeking to establish technical superiority over adversaries, including by developing weaponry that can be used in space. Several modern militaries have already invested heavily in developing the technology; many others are likely to have an interest in acquiring it.

DEW can be broadly defined as systems that produce 'a beam of concentrated electromagnetic energy or atomic or subatomic particles',[1] which is used as a direct means to incapacitate, injure or kill people, or to incapacitate, degrade, damage or destroy objects. Notably, this definition excludes sonic and ultrasonic weapons, which use sound waves to affect a target rather than electromagnetic waves. DEW currently take three primary forms:

- lasers capable of shooting down planes and missiles, or of using bright light to 'dazzle' or disorient people;
- weapons that use electromagnetic waves of other wavelengths, including millimetre waves or microwaves, that can be directed against human or hardware targets;
- weapons using particle beams to disrupt or damage a target's molecular or atomic structure.

Consideration of the current and anticipated development of these weapons suggests several areas of concern:

- Certain DEW may have the potential to circumvent existing legal restrictions and prohibitions on weapons, such as the prohibition on blinding laser weapons, creating comparable effects to prohibited systems but without falling within their technical definitions.
- Traditional interpretations of protective principles, including the prohibition on causing superfluous injury or unnecessary suffering to combatants, may be challenged by novel ways of inflicting physical and mental harm. Historically, systems that harm subjects through non-kinetic means have often been considered an issue of concern or as requiring special consideration.

- There appears to be little public data and considerable uncertainty about the environmental and health effects of DEW.
- Some DEW are promoted for use in various settings and for diverse purposes, which risks further blurring the boundary between law enforcement and war fighting, which traditionally have been subject to different normative regimes.

Based on these concerns, High Contracting Parties to the Convention on Certain Conventional Weapons (CCW) should:

- monitor research and development of DEW and assess their potential to challenge existing restrictions and prohibitions on weapons, or impact national and human security, peace and international security, arms control and disarmament;
- ensure respect for the letter and the spirit of the CCW and its protocols, reaffirm core values and long-standing principles these instruments give expression to and assess the conformity of novel mechanisms of harm with the prohibition on causing superfluous injury and unnecessary suffering, and the principle of distinction;
- reaffirm the prohibition on blinding laser weapons and assess whether CCW Protocol IV provides adequate protection against blinding in light of the risk to eyesight posed by developments in laser technologies and the evolving understanding of blindness;
- encourage transparency and integrate consideration of DEW in ongoing work, including in relation to weapons reviews in line with Article 36 of Additional Protocol I to the Geneva Conventions (API), ensure that a precautionary approach is applied and that assessments of environmental impact reflect the contemporary understanding of environmental law and protection.

CURRENT STATE OF PLAY

Advances in a range of sciences and technological applications are now feeding into significant progress in the development of lasers and other DEW.[2] Yet there is no consensus on their utility or desirability: for some, DEW will be at the forefront of a new wave of weaponry; others remain sceptical over both the desirability and the operational or strategic utility of such weapons systems. Many, particularly policy makers, have grown wary of what they perceive as a lack of delivery despite billions of dollars of investment.[3]

Lasers

Long a staple of science fiction, lasers[4] have captured the attention of militaries and policy makers since Albert Einstein first theorized about the possibility of 'stimulated emission' in 1917.[5] Now, several decades after the first laser was demonstrated in 1960, advances in a wide range of science disciplines have allowed laser technology to develop and be refined for both civilian and military use.

High-power lasers direct intensely focused beams of energy, and are usually powered by a chemical fuel, electric power or a generated stream of electrons.[6] Over the past 20 years, their use has accelerated in the commercial sector, where lasers are now routinely used for tasks such as metal cutting and welding. Lasers are also used by militaries and law enforcement agencies to designate targets, or in rangefinders to determine distances.

An attempt to develop 'battlefield' or 'tactical' laser weapons resulted in the development of laser weapons for anti-personnel use in the 1990s.[7] Such laser weapons, which were designed to cause permanent blindness, were prohibited in 1995 under Protocol IV to the CCW[8] before they were widely put to use. However, states pressed ahead with the development of laser systems for use against military hardware such as weapon platforms and vehicles, including unmanned aerial vehicles (UAVs or 'drones'), electronic equipment, and for missile defence, as well as so-called 'dazzlers', which target electronic sensors with infrared or invisible light.[9] They can also, when designed to emit visible light, be used against humans to 'dazzle', temporarily blind or disorient.[10]

Lasers have a number of effects on targets, which can be used to military advantage. Their most basic effect is heating, though in most lasers this is not sufficient to cause damage to hardware protected by military armour. At lower intensities, lasers can be used to produce a targeted flash or continuous beam that temporarily blinds or 'dazzles'. At higher intensities, they can create both heat and a mechanical impulse. Together, these properties can cause more extensive damage than when used alone.[11] By heating a target, the beam can deform or melt a hole in it; if pulsed and at much greater momentary intensities, a beam can cause vaporization, which in turn delivers an impulse to the surface of a target,[12] effectively transferring momentum to it and thereby damaging it through mechanical means.

The technology of military lasers currently under development falls into three broad categories: chemical lasers; electric-powered and solid-state lasers, including optical fibre lasers; and free-electron lasers, the newest and most complex.

- Chemical lasers are fuelled by a potentially toxic mix of chemicals that requires complex logistics to handle and transport, and which carries significant environmental and health risks.[13]
- Electric-powered and solid-state lasers[14] are more

stable and more easily transported, but are currently not very efficient as much of the energy required to produce a stable laser beam is lost as heat. Those working to further develop such lasers have struggled to develop sufficient cooling mechanisms to counteract this, though progress is being made.

- Free-electron lasers use a stream of electrons that passes through alternating magnetic fields to generate megawatt laser beams. They avoid both the difficulties of using chemical fuels (as in chemical lasers) and the issue of heat generation (as in electric and solid-state lasers), but they would be very big.

The recent advent of more portable and relatively cheap laser systems[15] driven by developments in nanotechnology,[16] battery power and optical fibres, has renewed enthusiasm for DEW broadly and laser weapons in particular. Lasers require large amounts of power to affect a target,[17] but the necessary additional power generators and sufficient cooling systems to counteract the thermal effects have traditionally taken up a considerable amount of space, space that combat-ready vehicles do not easily provide. On the other hand, lasers are not only increasingly portable, but more fuel efficient than they once were, and certainly less costly than their military alternative, often a missile.[18] This has been reflected in the advancement of tests: the US Navy trialled its laser weapons system (LaWS) to shoot down a ScanEagle UAV in 2013 and, in November 2014, to target small high-speed boats, marking the first successful demonstration of the operational use of such a weapon. The defence ministries of the UK and Russia have also reportedly confirmed that they are channelling extensive funding towards the development of laser, electromagnetic and plasma weapons.[19]

Microwave and millimetre-wave radiation technologies

Several militaries are already seeking to weaponize microwave and millimetre-wave radiation[20] technologies. Improvements in the underlying technology have enhanced the operational utility of electromagnetic weapons by making them more portable, improving the system's power density (the amount of energy stored per unit of volume), extending the range of the weapons and increasing the power output.

Such weapons can be used to disable electronic systems, including those embedded in military hardware and equipped with traditional electromagnetic pulse shielding. They work by bombarding the electronic systems that power or guide such military hardware with energy pulses that cause them to overload and shut down. China, Russia and the US are all reported to be actively pursuing the use of this technology in their military arsenals.[21] One Chinese microwave weapon, which recently won China's National Science and Technology Progress Award, is reportedly portable enough to be transported by standard military land and air vehicles.[22] It is also reported that the US has successfully tested one such weapon, CHAMP (the Counter-electronics High-powered Microwave Advanced Missile Project), an air-launched cruise missile with a high-power microwave payload.[23] Other microwave systems have been developed for use against missiles, improvised explosive devices (IEDs) and military vehicles.

Alternatively, weapons using millimetre waves (often, somewhat confusingly, called 'microwave weapons' in news reports) can be used against people by heating the skin to intolerably painful temperatures. Such weapons are envisaged for use in crowd control and dispersal, as well as at checkpoints and for perimeter security, but could have a wide range of applications. China has already developed such a weapon, commonly known as Poly WB-1, which will reportedly be used by its navy.[24] The best-known example, however, remains the US Active Denial System, a millimetre-wave source that produces an intense burning sensation in the skin, but leaves no visible mark. It was reportedly deployed in Afghanistan, but later withdrawn due to practical difficulties and concerns over how the use of the weapon might be perceived.[25]

Particle beams

During the Cold War, the US and USSR explored particle beam weapons for use both in the atmosphere and in space, but eventually abandoned the research as unfeasible for military application.[26] Particle beam weapons are closer to conventional kinetic weapons than laser or electromagnetic wave weapons in that they rely on kinetic energy. But instead of projectiles, they fire atomic or sub-atomic particles at a target with the aim of disrupting or destroying that target's molecular or atomic structure. Essentially, they rapidly heat the target's molecules and/or atoms to the point that the target material explodes; in their effects, they have been likened to lightning bolts.[27] These weapons can be divided into two types: weapons that use particles (for example, electrons or protons) that possess an electrical charge, which are suited for use within Earth's atmosphere, and neutral-particle beam weapons, made up of particles that are electrically neutral, which are better suited for use in space. Because of the way in which particle beams interact with a target, applying extra layers of protective material is unlikely to limit the damage inflicted.

The technology behind them – particle accelerators[28] – has been used for scientific research, including as colliders in the field of particle physics, and in a range of industrial and civilian applications including medical treatment. As yet, however, they have not been extensively developed as a weapons technology due to a number of technical challenges that make them impractical, not least the lack of weapon-grade and portable accelerators. To work in Earth's atmosphere, they would need an extremely large power supply. To work in space, they would require the ability to very precisely control the characteristics of the beam generated. Charged-particle beam weapons using current technology would also need to be large fixed installations, making them vulnerable to attack and rendering them of limited military use.[29] Thermal and electrostatic 'blooming' (a process by which the beam becomes distorted or diffused) and the difficulties of beam control have also curbed their current utility. According to one analysis, the 'size, weight, power constraints and inherent complexity' of neutral-particle beam weapons means that they are unlikely to 'see the light of day before 2025'.[30]

Many of these challenges – including generating enough energy, difficulties of focus and control, high costs and lack of portability – are shared across DEW. Key technical and financial barriers to their military operationalization remain, but progress is rapidly being made towards overcoming these, facilitated not just by direct investment, but also by significant advancements in a wide range of other technologies, most notably energy-generating and energy-storage technology, nanotechnologies and materials sciences. At the same time, other complementary technologies – for example, advanced image recognition that gives finer details of a target, thereby enabling the placement of a beam on the target's most vulnerable point – are increasing the combat utility of weapons that would rely on energy beams.

ADVERSE EFFECTS AND RISKS

DEW have not yet been widely used in conflict or other settings, but there is some research available on their effects – from accidents, worker protection and published military investigations.[31] DEW by their nature operate with varying intensities, and the duration of exposure and other physical and operational factors can produce a wide range of effects, from barely noticeable to deadly. Their technical characteristics, however, do raise a number of concerns over human physical and psychological welfare, as well as potential damage to civilian infrastructure.

The technologies behind DEW can be used to produce damaging physical effects, both in the short term and potentially in the long term, where questions remain over the long-term negative health effects of exposure and the effects of such exposure on individuals with pre-existing health conditions. In terms of immediate effects, lasers can produce anything from a glare or slight warming of the skin to blindness and severe skin burns.[32] Pulsed high-power lasers can produce plasma in front of a target, which then creates a blast wave with subsequent blunt trauma.[33] Even low-power laser weapons that are intended to temporarily blind or 'dazzle' can cause eye damage if used for extended periods or if the target is too close.[34] Electromagnetic radiation weapons can penetrate clothing to heat a person's skin, causing pain and potentially severe burns;[35] particle beam weapons can be expected to produce significant and potentially deadly burns as well as other injuries, including some consistent with ionizing radiation.[36] The one known instance of injury caused by a single hit from a higher-intensity particle accelerator resulted in the beam burning a hole directly through a physicist's skin, skull and brain. Though he survived through luck (the beam missed crucial parts of his brain), longer-term effects – many of them consistent with the radiation side effects seen in, for example, cancer treatments – included fatigue, loss of hearing, seizures and partial facial paralysis.[37]

There is little publicly available research on the anticipated psychological effects of DEW. They are likely to vary depending on individual vulnerability and state of health, the nature of the target and the context – for example, whether such weapons are used for policing a crowd in the open, in a confined space or in a battlefield situation – and the degree to which those people affected by the weapons understand what is happening and have training in how to anticipate and counter their effects. Electromagnetic radiation weapons have, to date, reportedly only been tested on trained soldiers; how civilians will react to the sensation of intolerable heating of the skin or to the disorienting effect of 'dazzler' lasers is unknown, but it is not unlikely that the use of such weapons against civilians or forces unfamiliar with them would cause significant panic and perhaps subsequent injury. It is also likely that the use of invisible 'rays' as a mechanism for causing harm would raise ethical and political concerns in some societies.

DEW, and particularly those that use electromagnetic pulse technology to overload or disrupt electrical systems and high-technology microcircuits, also present risks beyond those of direct physical and psychological harm. As critical civilian infrastructure increasingly relies on connected electronic and satellite technology, the impact of an electromagnetic pulse (EMP) device (also known as an 'E-bomb') has the potential to cause propagating failures in power, transport and communications networks.[38]

GOVERNANCE AND REGULATION

DEW are not authoritatively defined under international law, nor are they currently on the agenda of any existing multilateral mechanism. Nevertheless, there are a number of legal regimes that would apply to DEW. These range from national civilian-use regulations and guidelines to international humanitarian law (IHL) and human rights law that would constrain or preclude their use in certain situations.

The prospect of DEW raises questions under several bodies of international law, most notably those that place restrictions on the use of force. Some DEW are classified as 'non-lethal' or 'less-lethal' weapons, with proponents setting them apart from 'lethal' weapons.[39] In the civilian sphere, the sale, power and use of the technologies behind DEW – lasers, microwave beams and particle accelerators (and, in particular, ionizing radiation) – are all regulated to varying degrees,[40] suggesting that their potential to cause damage to human health has already been recognized under domestic legal regimes.

Human rights concerns over DEW primarily relate to the rights to life, health, freedom of assembly (particularly in the case of weapons that could be used for crowd control such as millimetre and microwave weapons), and the prohibition on cruel, inhuman or degrading treatment. Certain DEW are designed to act silently and invisibly – such as millimetre-wave weapons, which cause severe pain without necessarily leaving visible marks or physical evidence of their use – making their abuse easy to conceal and raising concerns about accountability for harm done and the availability of an effective remedy to victims. Depending on the width of beam used, they also risk adversely affecting bystanders.[41]

According to the 1990 UN Basic Principles on the Use of Force and Firearms by Law Enforcement Officials (BPUFF), an authoritative statement of international rules governing use of force in law enforcement, 'the development and deployment of non-lethal incapacitating weapons should be carefully evaluated in order to minimize the risk of endangering uninvolved persons, and the use of such weapons should be carefully controlled'.[42] This applies to the use of DEW for law enforcement, both during and outside of armed conflict, and irrespective of whether the weapons are used by police or military actors. Similarly, according to IHL – the primary legal regime that would govern the use of DEW for the conduct of hostilities – the right of the parties to the conflict to choose methods or means of warfare is not unlimited.[43] Under Article 36 of API, states have an obligation to assess all new weapons, means or methods of warfare to see whether their employment would fall foul of their legal obligations in some or all circumstances.[44]

There is a wide range of IHL provisions that could act to bar or limit the use of DEW. One form of DEW – blinding laser weapons – has already been expressly prohibited by Protocol IV to the CCW.[45] That instrument also requires that all feasible precautions, including practical measures, be taken in the employment of other laser systems to avoid permanent blindness to unenhanced vision,[46] and a strong argument can be made that the Protocol in effect also prohibits the deliberate use of other laser systems to blind.[47] However, the definition of 'permanent blindness' used in the Protocol may not accord with a modern understanding of 'visual impairment'.[48] It was already criticized as unscientific at the time of adoption, and states parties foresaw that it could be reconsidered in the future, taking into account scientific and technological developments.[49]

Despite claims regarding the accuracy of DEW, questions remain around the ability to target certain DEW at a specific military objective,[50] in compliance with the IHL rule of distinction and the prohibition of indiscriminate attacks.[51] Potential effects such as burning, eye damage or radiation sickness may raise concerns under the prohibition of causing superfluous injury or unnecessary suffering.[52] Such non-kinetic mechanisms of harm have historically provided grounds for concern regarding the acceptability of weapons. It is also questionable whether the intentional and unintended harm occasioned by the use of a DEW can be properly assessed, a requirement for compliance with the rules on proportionality and on precautions in attack.[53]

International environmental law may also be implicated in the use of certain DEW. Protection of the environment during armed conflict is increasingly emphasized as technological developments in new weaponry present new threats to the natural world.[54] In May 2016, the UN Environment Assembly agreed a resolution stressing the importance of environmental protections during armed conflict and urging states to comply with IHL environmental protections. Chemical lasers in particular may raise concerns under environmental law, due to their use of a toxic mix of chemicals to power the beam – chemicals that present a significant hazard in the case of an accident or if left abandoned.

DEW have been envisioned for use in outer space as well as within Earth's atmosphere, primarily as a form of directly attacking space assets such as satellites. The use of weapons in outer space is regulated by the 1967 Outer Space Treaty, which states that all use of outer space must be 'in accordance with international law'. DEW designed to deliver an electromagnetic blast or to target satellites raise concerns due to their potential impact on civilian infrastructure. Important questions remain about how the restrictions and prohibitions that could apply to DEW under, for example, IHL, would apply to their use in outer space.

Given the potential adverse effects of DEW and the uncertainties around their further development, a precautionary orientation, both politically and under international law, is warranted. Such an orientation should seek to address the questions and concerns that arise relating to the established norms and principles of IHL and international human rights law, as well as other bodies of law such as environmental and space law. As state use of DEW in military and domestic law enforcement operations increases, prompt action will be needed to ensure the risks they present to human health and dignity are adequately recognized, assessed and protected against.

Whether combat-ready DEW systems are a fast-approaching reality or remain a more distant proposition, these advances will need careful and comprehensive scrutiny in order to understand their potential humanitarian and other impacts. Yet they are not currently being actively considered on the agenda of any existing international mechanism.

NOTES

1 Joint Publication 1-02, 8 November 2010, p. 68, https://fas.org/irp/doddir/dod/jp1_02.pdf.

2 These include: nanotechnology, materials science, battery and energy delivery, greater computing power, better understanding of the variables that influence the use of DEW in Earth's atmosphere and adaptive optics.

3 J. D. Ellis, *Directed-Energy Weapons: Promise and Prospects*, Center for a New American Security, April 2015, p. 4, https://www.cnas.org/publications/reports/directed-energy-weapons-promise-and-prospects. Though fully developed and fielded DEW offer a significant reduction in costs when compared to their kinetic counterparts – a shot from a laser is significantly cheaper than a missile – their development thus far has proven incredibly costly, and significantly more investment would be needed in order to make them fully operational and combat-ready. It is unclear to what degree states will see these costs as a worthwhile investment. According to an estimate from the US Office of the Assistant Secretary of Defense for Research and Engineering/Research Directorate, the US Department of Defense has, since 1960, invested over $6 billion in directed energy science and technology initiatives (Center for Strategic and Budgetary Assessments, *Changing the Game: The Promise of Directed-Energy Weapons*, 2012, p.48, https://csbaonline.org/uploads/documents/CSBA_ChangingTheGame_ereader.pdf). In January 2017, the UK reportedly awarded a £30 million contract to a consortium of European defence firms to produce a prototype laser weapon (P. Rincon, 'UK Military to Build Prototype Laser Weapon', *BBC News*, 5 January 2017, https://www.bbc.co.uk/news/science-environment-38510344). The US 2017 Defense Bill also reportedly authorized some $328 million for the development and procurement of directed energy weapons (S. Snow, 'Congress OKs More Money, Gets Serious About Laser Weapons in Defense Bill', *Military Times*, 28 December 2016 https://www.militarytimes.com/news/pentagon-congress/2016/12/28/congress-oks-more-money-gets-serious-about-laser-weapons-in-defense-bill/). Full text of bill available at https://www.govtrack.us/congress/bills/114/s2943/text.

4 The term 'laser' was originally an acronym for Light Amplification and Stimulated Emission of Radiation.

5 'Einstein Predicts Stimulated Emission', 14(8) *APS News*, (August/September 2005), https://www.aps.org/publications/apsnews/200508/history.cfm.

6 Chemical lasers have historically succeeded in producing megawatt-level outputs, but they are unwieldy and logistically difficult to transport and use. In recent decades, there has been a shift in focus to solid-state lasers, which are often more portable and fuel efficient; they are, rather, in the kilowatts to tens-of-kilowatts class. More recently, free-electron lasers – usually very large and immobile – have garnered interest due to their ability to circumvent some of the technical challenges that have hampered attempts to operationalize other types of lasers.

7 In 1995, Human Rights Watch (HRW) reported that the US, China, Russia, Israel and several European states were developing blinding laser weapons (HRW, *United States: U.S. Blinding Laser Weapons*, Human Rights Watch Arms Project, https://www.hrw.org/reports/1995/Us2.htm.

8 Protocol IV to the 1980 Convention on Certain Conventional Weapons (CCW) prohibits the use of blinding laser weapons as a means or method of warfare, as well as their transfer to any state or non-state actor.

9 Russia's Sokol Eshelon project is reportedly working to develop a laser to blind the sensors of an enemy satellite (D. Cenciotti, 'Russia Has Completed Ground Tests of Its High-Energy Airborne Combat Laser', *Business Insider*, 5 October 2016, https://www.businessinsider.com/russia-high-energy-airborne-combat-laser-system-2016-10?r=UK).

10 One example is the PHaSR (Personnel Halting and Simulation Response) developed by the US Air Force and designed to stun or 'dazzle' a target (E. D. Blaylock, 'New Technology "Dazzles" Aggressors', U.S. Air Force, 2 November 2005, https://archive.is/20120721195102/http:/www.af.mil/news/story.asp?storyID=123012699).

11 P. E. Nielsen, *Effects of Directed Energy Weapons*, 2009, p. 170.

12 'Mechanical effects result when momentum is transferred to a target by vapor shooting from it. In effect, the vapor serves as a small jet, and exerts a reaction force back on the target' (ibid, p. 175).

13 D. Pudo and J. Galuga, 'High Energy Laser Weapon Systems: Evolution, Analysis and Perspectives', 17(3) *Canadian Military Journal* (2017), http://www.journal.forces.gc.ca/Vol17/no3/PDF/CMJ173Ep53.pdf.

14 These include optical fibre lasers like the US Navy's LaWS.

15 Solid-state lasers use rods, slabs or discs of crystal to produce the beam, whereas fibre lasers use thin optical fibres that are lightweight and more compact (A. Extance, 'Military Technology: Laser Weapons Get Real', 521(7553) *Nature* (May 2015), https://www.nature.com/news/military-technology-laser-weapons-get-real-1.17613).

16 H. Nasu, 'The Future of Nanotechnology in Warfare', *The Global Journal*, 4 July 2013, http://www.theglobaljournal.net/article/view/1132/.

17 E.g., to destroy an anti-ship cruise missile, a laser would require a beam of 500 kW and demand megawatts of power (A. Robinson, 'Directed Energy Weapons: Will They Ever Be Ready?', *National Defense*, 1 July 2015, http://www.nationaldefensemagazine.org/articles/2015/7/1/2015july-directed-energy-weapons-will-they-ever-be-ready).

18 A recent report set the 'cost per kill' at about $30 for a 'pre-prototype' laser-equipped vehicle designed to target drones and missiles (J. Kester, 'Army, Defense Companies Making Renewed Push for Laser Weapons', *Foreign Policy*, 12 Oct 2017, https://foreignpolicy.com/2017/10/12/army-defense-companies-making-renewed-push-for-laser-weapons/). See also UK Defence Science and Technology Laboratory, 'Dragonfire: Laser Directed Energy Weapons', press release, 13 September 2017, https://www.gov.uk/government/news/dragonfire-laser-directed-energy-weapons.

19 T. Batchelor, 'Russia Developing Laser, Electromagnetic and Plasma Weapons, Kremlin Says', *Independent*, 22 January 2017, https://www.independent.co.uk/news/world/europe/russia-laser-electromagnetic-plasma-weapons-military-kremlin-a7540716.html. The UK is reportedly aiming to develop a ship-mounted laser cannon by 2020 (E. MacAskill, 'Royal Navy Aims to Put Laser Weapon on Ships by 2020', The Guardian, 15 September 2015, https://www.theguardian.com/uk-news/2015/sep/15/royal-navy-death-ray-laser-cannon-ships-2020; UK Defence Science and Technology Laboratory, 'Dragonfire'.

20 Microwaves are a band of radio frequencies in the electromagnetic spectrum ranging in frequency from 300 MHz to 300 GHz with a wavelength ranging from 100 cm to 0.1 cm. This includes millimetre waves, electromagnetic radiation in the frequency range of 30 GHz to 300 GHz with a wavelength in the 10 mm to 1 mm range.

21 B. Gertz, 'Report: China Building Electromagnetic Pulse Weapons for Use Against U.S. Carriers', *The Washington Times*, 21 July 2011, https://www.washingtontimes.com/news/2011/jul/21/beijing-develops-radiation-weapons/; A. Withnall, 'Russia Demonstrates First "Microwave Gun" That Can Disable Drones and Missiles From up to Six Miles Away at Army-2015', *Independent*, 16 June 2016, https://www.independent.co.uk/news/world/europe/russia-demonstrates-its-first-microwave-gun-that-can-disable-drones-and-missiles-from-up-to-six-10323243.html.

22 J. Lin and P. W. Singer, 'China's New Microwave Weapon Can Disable Missiles and Paralyze Tanks', *Popular Science*, 26 January 2017, https://www.popsci.com/china-microwave-weapon-electronic-warfare.

23 Boeing, 'CHAMP – Lights Out', 22 October 2012, http://www.boeing.com/features/2012/10/bds-champ-10-22-12.page.

24 A. Griffin, 'China Reveals Long-Range Heat Ray Gun', *Independent*, 15 December 2014, https://www.independent.co.uk/life-style/gadgets-and-tech/news/china-reveals-long-range-heat-ray-gun-9925713.html.

25 B. Buch and K. Mitchell, 'The Active Denial System: Obstacles and Promise', Policy White Paper, Global Research Institute, William & Mary, April 2013, p. 22, https://www.wm.edu/offices/global-research/projects/pips/_documents/pips/2011-2012/active_denial_system.pdf.

26 A. Kochems and A. Gudgel, 'The Viability of Directed-Energy Weapons', The Heritage Foundation, 28 April 2006, https://www.heritage.org/node/16798/print-display.

27 R. M. Roberds, 'Introducing the Particle-Beam Weapon', *Air University Review*, July–August 1984, https://www.bibliotecapleyades.net/scalar_tech/devvision/devvission-appendix-j.pdf.

28 The best-known use of a particle accelerator is in the Large Hadron Collider at CERN, which aimed to create Higgs Boson particles in order to study them.

29 A. K. Maini, 'Directed Energy Weapons: Particle Beam Weapons', Electronicsforu.com, 12 August 2016, https://electronicsforu.com/market-verticals/aerospace-defence/directed-energy-weapons-particle-beam.

30 Ibid.

31 See J. Altmann, *Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons? Physics Analyses and Inferences*, Forschung DSF no 16, Deutsche Stiftung Friedensforschung, 2008, https://www.ssoar.info/ssoar/bitstream/handle/document/26039/ssoar-2008-altmann-millimetre_waves.pdf?sequence=1&isAllowed=y&lnkname=ssoar-2008-altmann-millimetre_waves.pdf.

32 B. Anderberg and M. L. Wolbarsht, *Laser Weapons: The Dawn of a New Military Age*, 2013, p. 81.

33 N. Davison, *'Non-Lethal' Weapons*, 2009, p. 157.

34 W. Knight, 'US Military Sets PHASRs to Stun', *New Scientist*, 7 November 2005, https://www.newscientist.com/article/dn8275-us-military-sets-laser-phasrs-to-stun/.

35 Altmann, *Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons?* p. 18. For an independent review of the health effects of the Active Denial System (ADS) in particular, see also J. M. Kenny et al, *A Narrative Summary and Independent Assessment of the Active Denial System*, Penn State Applied Research Laboratory, 2008, https://jnlwp.defense.gov/Portals/50/Documents/Future_Non-Lethal_Weapons/HEAP.pdf.

36 Theoretical effects of particle beam weapons are largely drawn from the known side effects of civilian-use particle beams. Particle accelerators and beams are used in radiotherapy as a medical treatment; known side effects in the short and long term vary depending upon the area of body being treated, but usually include skin damage (including radiation burns) and tiredness.

37 In 1978, Russian scientist Anatoli Petrovich Bugorski accidentally put his head in the path of a Soviet particle accelerator whilst working as a researcher at the Institute for High Energy Physics (J. Frolich, 'What Happens if You Stick Your Head in a Particle Accelerator?', *The Atlantic*, 12 January 2017, https://www.theatlantic.com/science/archive/2017/01/what-happens-when-you-stick-your-head-in-a-particle-accelerator/512927/; M. Gessen, 'The Future Ruins of the Nuclear Age', *Wired*, 1 December 1997, https://www.wired.com/1997/12/science-2/).

38 A report by the US Commission established to assess the threat posed by an EMP attack concluded that the US would suffer 'long-term, catastrophic consequences' due to societal dependence on the electrical power system and overall vulnerability to attack. EMP Commission, Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, April 2008, https://apps.dtic.mil/dtic/tr/fulltext/u2/a484672.pdf.

39 Both enthusiasm for and concerns over DEW have fallen under a larger debate about the viability and place of 'non-lethal' weapons in both domestic policing and situations of armed conflict, as well as the appropriate forms of regulation and legal redress. Some proponents initially suggested that existing international law be modified or discarded with regard to these weapons; opponents countered by insisting they must comply with existing international law. For an overview, see D. P. Fidler, 'The Meaning of Moscow: "Non-Lethal" Weapons and International Law in the 21st Century', 87(859) *International Review of the Red Cross* (September 2005), https://www.icrc.org/en/doc/assets/files/other/irrc_859_fidler.pdf; N. Lewer and M. Davison, 'Bradford Non-Lethal Weapons Research Project: Research Report No. 7', University of Bradford, May 2005, https://bradscholars.brad.ac.uk/bitstream/handle/10454/3999/BNLWRPResearchReportNo7_May05.pdf?sequence=1.

40 E.g., in the US, it is illegal under the FAA Modernization and Reform Act (2012) to shine a laser beam at or in the flight path of an aircraft; several states have set out varying classes of laser products with accompanying safety standards; and products emitting electronic radiation, including microwaves, are similarly regulated to eliminate or minimize the risks of exposure.

41 The US ADS uses 1.5 m-wide beams of millimetre waves that range up to 1000 ft. It is unclear if this width is variable, or if it is adhered to in other millimetre-wave systems (Non-Lethal Weapons Program, US Department of Defense, 'Active Denial System FAQs', https://jnlwp.defense.gov/About/Frequently-Asked-Questions/Active-Denial-System-FAQs/.

42 Principle 3, 1990 Basic Principles on the Use of Force and Firearms by Law Enforcement Officials.

43 Art 35(1), API.

44 Art 36, API.

45 Protocol on Blinding Laser Weapons (1995), annexed to the framework Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons (CCW). The prohibition is considered by the International Committee of the Red Cross (ICRC) to be a norm of customary international law applicable in both international and non-international armed conflicts (ICRC, Customary IHL study, Rule 86).

46 Art 2, 1995 CCW Protocol IV.

47 ICRC, Customary IHL study, Rule 86.

48 See World Health Organization, 'Change the Definition of Blindness', International Classification of Diseases Updated and Revision Platform, https://www.who.int/blindness/Change%20the%20Definition%20of%20Blindness.pdf?ua=1.

49 Final Declaration of the Review Conference, Review Conference of the States 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, Final Report, UN doc CCW/CONF.I/16(Part I), Annex C, 1996. For more information, see 'Blinding Laser Weapons', *Weapons Law Encyclopedia*, http://www.weaponslaw.org/weapons/blinding-laser-weapons.

50 E.g., atmospheric conditions can impact beam quality and, in turn, the ability of militaries to effectively operate DEW. This is particularly noticeable in laser beams, where the air turns to plasma as the beam moves through it, causing the beam to lose focus – so-called 'blooming'. To hit targets at a great distance, the quality of the beam generated will need to be significantly greater than that needed for current industrial uses. The difficulty in sufficiently concentrating and targeting the beam, taking account of atmospheric variations, raises significant concerns over military effectiveness and harm to civilians. See, e.g., P. Sprangle et al, High-Power Lasers for Directed-Energy Applications, 54(31) *Applied Optics* (2015). Complex and challenging operational environments can also be expected to exacerbate the inherent difficulties in the operation of DEW, as well as render more logistically difficult their maintenance (D. H. Titterton, *Military Laser Technology and Systems*, 2015, pp. 60–61.

51 Art 51(4), API; ICRC, Customary IHL study, Rules 11 and 71.

52 Art 35(2) API; ICRC, Customary IHL study, Rule 70.

53 Arts 51(5)(b) and 57(2)(a)(iii), API; ICRC, Customary IHL study, Rules 14, 15.

54 See the International Law Commission's draft principles on the protection of the environment in relation to armed conflict, UN doc A/71/10, http://legal.un.org/docs/?path=../ilc/reports/2016/english/chp10.pdf&lang=EFSRAC; UN Environment Programme, *Protecting the Environment During Armed Conflict: An Inventory and Analysis of International Law*, 2009, https://www.un.org/zh/events/environmentconflictday/pdfs/int_law.pdf.

HYPERSONIC WEAPONS

DISCUSSION PAPER FOR THE CONVENTION ON CERTAIN CONVENTIONAL WEAPONS (CCW)

GENEVA, FEBRUARY 2019

Hypersonic weapons have in recent years attracted attention from militaries, governments and, increasingly, multilateral institutions following reports of successful prototype testing. In 2018, the UN Secretary-General highlighted hypersonic glide vehicles and cruise missiles in a report on the role of science and technology in the context of international security and disarmament, and called on the international community to 'remain vigilant in understanding new and emerging weapon technologies that could imperil the security of future generations'.[1] The development of hypersonic weapons is said to pose a challenge to strategic missile defences and raise wider international security concerns due to their 'considerable potential to further complicate strategic relations, encourage new arms competition and endanger stability'.[2]

Several modern militaries are currently working to develop hypersonic weapons, which after decades of research could soon be fielded in significant numbers.[3] Predictions over how quickly this may occur, absent any multilateral efforts to curb or halt the weaponization of hypersonic technology, vary.[4] NATO has commented that 'the systems being developed and tested today are mature enough to lead us to believe they will be fielded in the foreseeable future'.[5] Hypersonic glide vehicles could be deployed within five years.[6]

'Hypersonic' is generally understood to refer to flight within the atmosphere at speeds above Mach 5 (five times the speed of sound), or above around 6,100 km per hour. One focus of military interest is hypersonic missiles that can travel at approximately 5,000 to 25,000 km per hour (or between 1.4 and 7 metres per second)[7] – up to 25 times faster than a standard airliner.

The development and potential future deployment of hypersonic weapons illuminates a number of broader themes and questions that deserve attention from the perspective of multilateral weapons control, including within the framework of the Convention on Certain Conventional Weapons (CCW), a 'hybrid treaty' that sits at the intersection of arms control, disarmament and humanitarian law:[8]

- The development of hypersonic weapons is driving research and development of technologies to defend against them, including kinetic interceptors, electromagnetic railguns and high-power lasers,[9] which may also have potential uses as offensive weapons,[10] in turn spurring further armament reaction cycles. Hypersonic weapons are also more expensive than existing alternatives. This has implications for international stability, security, peace and sustainable development.

- In certain scenarios, hypersonic weapons may provide less time to respond, compared to existing cruise and ballistic missiles. This can be expected to compress decision time, contributing to the trend towards increasing reliance on artificial intelligence, both to inform human decision makers and to automate certain processes,[11] raising concern about the risk inherent in decision-making under time pressure. Speed of action is a common thread in the hypersonic and autonomous weapons debates.
- Both nuclear and conventional hypersonic weapons affect nuclear stability and thereby international peace and security. This complicates efforts aimed at preventing or limiting these weapons, but also offers additional avenues and opportunities for multilateral control.
- Hypersonic weapons are likely to increase the risk of pre-emptive strikes, accidents, miscalculations, conflict instability and rapid conflict escalation due to their potential to shorten decision times and the nuclear ambiguity surrounding them, among other reasons. The introduction of hypersonic weapons risks undermining long-standing arms control and disarmament efforts in various domains.
- These factors underscore the need to consider the wider arms control and disarmament implications of specific weapon developments, and to consider the intersections of categories used to delimit the scope of multilateral weapons control mechanisms. These tend to approach different weapons largely in isolation from each other, creating potential gaps or responses that inadequately account for cross-cutting issues.
- There is no shortage of suggestions for the control of hypersonic weapons. What has been missing thus far is the political will to take them forward. As with other (emerging) weapon technologies, progress in this regard does not only require agreeing on where to draw the line between the acceptable and the unacceptable on technical grounds.[12] It is also calls for efforts to conceptualize the issue and organize policy work in such a way that those who risk being affected by these weapons are empowered to take measures for their control.

CURRENT STATE OF PLAY

The development of hypersonic technologies for military use has been pursued by states since the 1940s, when attempts to establish space-ready vehicles produced the first piloted supersonic aircraft flight to break the sound barrier, with several decades of research programmes that at best produced mixed results.[13] Scientific and technological advances in recent years have, however, made practical hypersonic weapons appear to be within reach. Most prominently, China, Russia and the US have pursued, and claimed varying successes in the testing of, hypersonic missiles.[14]

There are currently two primary streams of development in hypersonic weapons:

- **Hypersonic glide vehicles** (HGVs)[15] are typically launched by rocket into the upper atmosphere and released at an altitude of between 40 and 100 km from where they glide to their target at hypersonic speed. HGVs have a reach comparable to ballistic missiles but they fly at a lower altitude, and a negligible portion of their flight path follows a ballistic trajectory.[16] This results in the time between detection by ground-based sensors and impact being shorter compared to a ballistic missile's re-entry vehicle.[17] HGVs are manoeuvrable during their glide phase and can be redirected in flight to a different target than initially planned.[18]
- **Hypersonic cruise missiles** (HCMs), sometimes referred to as 'air-breathing cruise missiles', are powered during their entire flight. They need to be accelerated to a speed of Mach 5 before an advanced jet (ramjet, scramjet) engine can take over to maintain speed.[19] HCMs could be ground-, air- or ship-launched and would likely fly at an altitude of 20 to 30 km,[20] beyond the reach of most current air-to-surface missile defence systems. They could reach targets that are 1000 km away within minutes.

In addition, missile systems, such as Russia's Iskander-M, that feature aerodynamic manoeuvring at high-supersonic speeds or manoeuvring ballistic missile warheads are sometimes described as hypersonic.[21] Projectiles fired from electromagnetic or powder guns may also reach low-hypersonic speeds. These applications may complicate the debate and potential regulatory efforts regarding hypersonic weapons but are beyond the scope of this paper.[22]

In the US, current attempts to develop hypersonic weapons began in 2003 under the Conventional Prompt Global Strike programme, which seeks to develop a system that can deliver a precision-guided airstrike anywhere in the world within one hour.[23] In 2018, the Pentagon indicated that the US Army, Navy and Air Force would work together to develop and deploy a common hypersonic glide vehicle by the early 2020s.[24]

Information on defence technology developments in states other than the US tends to be less available, with programmes shrouded in secrecy, but reports suggest that in November 2017, China flight-tested a hypersonic glide vehicle, the DF-17, which is predicted to reach operational capacity in 2020. Russia's version of a hypersonic cruise missile, the ship-based 3M22 Zircon/Tsirkon, is reported to be at a similarly advanced stage of development with successful tests in late 2018.[25] In December 2018, Russia also successfully tested its 'Avangard' system, which will reportedly be deployed in 2019[26] and has been described as a nuclear-capable long-range hypersonic glider.[27] Over 20 additional states, including France, India, Australia, Germany and Japan are now thought to be pursuing the technology for military purposes.[28]

Hypersonic weapons are expected to combine significantly higher speeds with enhanced manoeuvrability. They would enable offensive missile strikes to destroy targets at great distances. They are designed to operate at altitudes that make them particularly 'difficult to detect, either from the ground, because of the limited viewing angle, or from space because of background clutter',[29] and therefore offer a way of circumventing current advanced defence systems built to intercept ballistic missiles.[30] As one analyst has summarized, '[t]hey are able to evade and conceal their precise targets from defences until just seconds before impact. This leaves targets with almost no time to respond.'[31]

There is, however, considerable ambiguity regarding precise goals,[32] – in certain cases purposefully maintained by some and severely criticized by others – especially regarding their role in nuclear war and deterrence ('nuclear ambiguity').[33] This uncertainty adds to the difficulty of assessing from public information the targets and warhead types under development. HGMs and HCMs could be equipped with a nuclear or conventional (explosive) warhead and they could damage certain targets by way of their high kinetic energy alone.[34] Some commentators therefore describe hypersonic weapons as 'most appropriate for hard and deeply buried targets'.[35] Others deem hypersonic weapons most suited for use against 'fixed, soft targets'.[36] Among the diverse targets mentioned by commentators are command and control centres and bunkers, radar and surveillance systems, missile launch vehicles[37] and other 'strategic' assets,[38] as well as island bases, shore facilities and ships,[39] including ships in ports.[40]

Though the technology is being developed and refined, notable technical barriers remain to the operationalization and deployment of hypersonic weapons.[41] In addition to these technical challenges, questions remain about the economic viability of hypersonic weapons programmes, which thus far have proven hugely expensive to fund.[42] The altitude at which they are designed to fly makes in-atmosphere testing, modelling and simulation difficult and costly, not least because hypersonic wind tunnels need to be constructed and engineered to produce flight-representative conditions.

ADVERSE EFFECTS AND RISKS

Concerns about hypersonic weapons centre on their implications for international stability, security and peace. For states relying on advanced missile defence systems (and by extension, their allies), hypersonic missiles represent a circumvention of their systems. This is motivating an effort to extend capabilities to intercept hypersonic weapons, including the development of directed energy weapons and deployment of space-based sensors, with space weapons potentially to follow.[43]

Furthermore, the operationalization of hypersonic weapons could negatively affect the security of all states and populations. Key concerns include:

- The difficulty of predicting the trajectory and target of a hypersonic weapon and the possibility of fitting it with a nuclear or a conventional warhead could increase the risk of mistaking a conventionally-armed missile for a nuclear-armed one or associating it with a completely disarming attack. This could prompt states to put their militaries on a 'state of hair-trigger readiness'.[44] It could also lead to a greater tendency to use pre-emptive strikes against states that possess hypersonic technology or induce 'a reconsideration of traditional second-strike calculations'.[45] Attempts by states to develop effective defence systems against hypersonic weapons may increase the militarization of space.[46] Taken together, these dynamics would increase conflict instability and the risk of rapid conflict escalation, run counter to de-alerting efforts and undermine long-standing arms control and disarmament efforts.
- The compressed timeline for decision-making forced by hypersonic weapons could further reduce states' ability to exert a measure of control over the escalation of tensions and conflict and increase the risk of miscalculations and accidents. It could also erode democratic control and oversight of uses of force, as there is a risk that the need to react swiftly incites some states to move authorization to conduct military strikes down the chain of command.
- A costly hypersonic weapons-driven arms race could also undermine the achievement of the Sustainable Development Goals.

GOVERNANCE AND REGULATION

No multilateral weapons control body has thus far given hypersonic weapons focused attention[47] despite the enthusiasm generated in certain quarters and widespread agreement among arms control experts that the developing arms race in hypersonic weapons is wasteful, destabilizing and dangerous.[48] Tackling hypersonic weapons is complicated by the dynamics of both nuclear and conventional arms control, and challenges facing multilateral missile control.[49]

There are, however, a number of existing regulatory frameworks that limit the use of, as well as other activities involving, hypersonic weapons:

- Although there is no universally accepted norm or instrument that governs missiles in all their aspects, multilateral regimes to control access to missile technologies with a view to maintaining international stability or security offer some controls on hypersonic weapons. An example is the Missile Technology Control Regime (MTCR), a politically binding agreement subscribed to by 35 states with the aim of limiting the spread of missiles and other unmanned air vehicles capable of delivering biological, chemical or nuclear payloads.[50] The MTCR Annex Handbook 2017 mentions 'hypersonic glide vehicles' as one potential type of Manoeuvring Re-entry Vehicle (MARV) controlled under Category I.[51] However, Category I only captures re-entry vehicles 'if they meet the criteria of a 500-kg payload and a greater than 300-km range and are not designed as a peaceful payload'.[52] As hypersonic weapons can inflict damage with a small conventional payload or their kinetic energy alone, many types may fall below this weight threshold.[53] In addition, certain countries developing hypersonic weapons, like China, do not participate in the regime.[54]

- The use of hypersonic missiles is, in any case, subject to international legal rules on the resort to force by states (jus ad bellum) and constrained by the rules of international humanitarian law governing the conduct of hostilities. Certain scenarios involving hypersonic weapons, such as their use 'to interdict illicit transfers of nuclear weapons, material, or technology among rogue states, terrorist groups, and criminal networks'[55] raise concerns regarding compliance with Article 2(4) of the UN Charter and peremptory norms of customary international law.[56] Consideration should also be given – including in the legal review of new hypersonic weapons [57] – to how the use of hypersonic weapons affects the protection of civilians against the effects of hostilities,[58] notably in light of concerns regarding their 'inadequate precision'.[59]

- The threat or use of hypersonic weapons with a nuclear warhead would 'generally be contrary to the rules of international law applicable in armed conflict, and in particular the principles and rules of humanitarian law'.[60] Like other nuclear weapons, they would be prohibited under the 2017 Treaty on the Prohibition of Nuclear Weapons (not yet in force) and limited by the Nuclear Non-Proliferation Treaty (NPT), nuclear weapons free zone treaties and other nuclear disarmament and arms control instruments.

Arms control experts from different schools of thought have voiced concern that hypersonic weapons might threaten international stability and/or security and have suggested avenues to either prevent their emergence or deployment or to control their possession or limit their use:

- Ghoshal considers that **a complete ban** on hypersonic weapons would be the 'ideal' and 'the only solution viable for preventing proliferation challenges in future', but acknowledges that such a ban may not be accepted by states who have invested heavily in these weapons already.[61]

- Based on the premise that states would not make substantial investments in or rely on untested hypersonic weapons, Gubrud has proposed an international hypersonic missile **test ban**,[62] starting with an informal **moratorium** among those countries currently pursuing this technology.[63] A similar proposal was subsequently advanced by a US Air Force officer.[64] Aune et al consider a test ban to be the 'best mechanism for control',[65] but questions have been raised about unequal access to the means of verification, possible impacts on civilian (peaceful) applications of hypersonic technologies,[66] the risk of replicating or further entrenching power imbalances between have and have-not states, and the willingness of states that have dedicated large sums towards the development of hypersonic weapons to support a test ban.[67]

- A **targeting ban** has also been suggested, either as a unilateral risk reduction measure by which a state would refrain from developing strategies that involve using hypersonic missiles against nuclear targets and command, control and communications centres,[68] or as multilaterally agreed **limitations on targets or missions** assigned to hypersonic weapons.[69] Similarly, Podvig suggests banning nuclear launched cruise missiles or nuclear boost-glide systems to eliminate 'nuclear ambiguity'.[70] Whereas this may help to increase nuclear stability and reduce the risk of inadvertent escalation and miscalculation, it does not prevent the emergence, deployment and spread of hypersonic weapons. These measures may also be perceived as being directed only at those states that acknowledge a nuclear role for hypersonic weapons, letting others 'off the hook'.

- Various **non-proliferation measures** have also been proposed. Aune et al suggest an agreement modelled after the NPT, 'where non-hypersonic states agree to not pursue the technology, and existing hypersonic states agree to keep the hardware and expertise required for hypersonic technology to themselves'.[71] In a recent report for RAND Corporation, Speier et al propose an initial **tripartite agreement** between Russia, China and the US to limit the proliferation of certain hypersonic technologies, followed or paralleled by an agreement by a broader set of states on export controls, within or outside of the MTCR.[72] More or less far-reaching **amendments to the MTCR and similar instruments** have also been proposed.[73] Speier et al recommend a policy of export denial for complete hypersonic delivery vehicles and major subsystems coupled with a policy of case-by-case export reviews for scramjets and other hypersonic engines and components, fuels for hypersonic use and relevant sensors, navigation, communication, simulation and testing equipment.[74] Siddhartha suggests including 'Lifting Bodies' or 'Hypersonic Gliders' and certain of their components among the controlled items.[75] Van Ham proposes broadening the scope of the MTCR to control 'Weapons of Mass Effect' (rather than mass destruction) so as to cover 'hypersonic kinetic energy weapons'.[76] Whereas there is some optimism about the effectiveness and political feasibility of export controls on hypersonic missiles,[77] non-proliferation measures are always vulnerable to the criticism of replicating the oft-resented 'haves and have-nots' dynamics,[78] and only partially address the destabilizing potential of current hypersonic weapon developments. They do not prevent further development of hypersonic capabilities by states already engaged on this path and other states may therefore be unwilling to forego potential future acquisition.

- Zhao has suggested that hypersonic weapons should be 'accounted for' in **arrangements limiting or reducing strategic arms**,[79] for example, within the framework of the successor to the New Strategic Arms Reduction Treaty (New START) concluded between the US and Russia and expected to last into 2021.[80] This would go some way in addressing the risks of 'entanglement' of conventional and nuclear aspects, but bilateral agreements do not bind other relevant states, and there appears to be limited appetite for such cooperative measures between the US and Russia at present.[81]

- Others have emphasized the importance of **confidence-building measures** similar to those pursued with regard to ballistic missiles, such as giving advance notice of tests, placing restraints on the location of tests and specifying 'that hypersonic missiles will be used only with non-nuclear warheads',[82] and have identified **transparency measures** such as data exchanges and notifications as realistically achievable options.[83]

- The organization of an **international conference** to discuss the issue has also been proposed,[84] and the Secretary-General has tasked the UN Office for Disarmament Affairs and the UN Institute for Disarmament Research to **study** the peace and security implications of long-range conventional weapons, including those using hypersonic technologies, to enable his Advisory Board on Disarmament Matters to 'make practical recommendations for arms control measures'.[85]

Despite some shortcomings, these proposals point to valuable avenues to explore, in combination or individually. Inaction risks complicating other arms control endeavours, especially in relation to nuclear disarmament, missile control and efforts to restrain the weaponization of outer space.[86] Generating the political will to move forward is, thus, critical. At present, there is a tendency to expect that a small number of states – those who actively pursue the development of hypersonic weapons – champion control initiatives. This leaves the majority of states and other actors without a stake in the debate despite the fact that the effects of hypersonic weapons will be felt by states and communities worldwide. Recognizing how hypersonic weapons threaten our common security may help mobilize political will to move forward. As the UN Institute for Disarmament Research (UNIDIR) and the UN Office for Disarmament Affairs (UNODA) underline in a recent report: 'it is feasible and desirable for States to pursue a multilateral process that would address issues related to the development of hypersonic weapons'.[87]

NOTES

1 Report of the Secretary-General on current developments in science and technology and their potential impact on international security and disarmament efforts, UN doc A/73/177, 17 July 2018, §3.

2 UN Office for Disarmament Affairs (UNODA), *Securing Our Common Future: An Agenda for Disarmament*, 2018, p. 30, https://www.un.org/disarmament/publications/more/securing-our-common-future/.

3 J. M. Acton, 'Hypersonic Boost-Glide Weapons', 23(3) *Science & Global Security* (2015) 191–192; P. Podvig and A. Stukalin, 'Russia Tests Hypersonic Glide Vehicle', *Jane's Intelligence Review*, 4 June 2015; R. Kheel, 'Russia, China Eclipse US in Hypersonic Missiles, Prompting Fears', *The Hill*, 27 March 2017, http://thehill.com/policy/defense/380364-china-russia-eclipse-us-in-hypersonic-missiles-prompting-fears.

4 Besser et al suggest that 'the boost-glide vehicle is likely to be the first operational system, as the number of global successful tests of prototype systems outpaces any other hypersonic technology by far. An operational system is attainable by 2022–2025'. They also note that '[o]perational readiness of long-range, air-launched hypersonic cruise missiles is very unlikely within the next decade, because of the higher complexity of a powered vehicle in comparison to a glider, but should be attainable within 20 years' (H. Besser et al, 'Hypersonic Vehicles: Game Changers for Future Warfare?', 24 *Journal of the Joint Air Power Competence Centre (JAPCC)* (2017) 21–22, https://elib.dlr.de/113912/1/Hypersonic%20Vehicles%20-%20JAPCC%20Journal%20-%20Volume%2024_2017.pdf).

5 NATO Science and Technology Board, *STO Tech Trends Report 2017*, 8 August 2017, p. 20, https://www.nato.int/nato_static_fl2014/assets/pdf/pdf_topics/20180522_TTR_Public_release_final.pdf. Russia says it will deploy its Avangard system 'which includes a hypersonic glide vehicle carried on a UR-100NUTTH/SS-19 missile' in 2019 (P. Podvig, 'Avangard System Is Tested, Said to Be Fully Ready for Deployment', *Russian Strategic Nuclear Forces*, 26 December 2018, http://russianforces.org/blog/2018/12/avangard_system_is_tested_said.shtml).

6 Report of the Secretary-General on current developments in science and technology, §29.

7 'Missiles and other flying vehicles can travel in three speed ranges – subsonic, supersonic, and hypersonic. Subsonic missiles fly at less than the speed at which sound travels (Mach 1), about 1,000 kilometers per hour (km/hr). Supersonic missiles fly above Mach 1. They are generally regarded as flying between Mach 1 and Mach 5, about 1,000 to 5,000 km/hr' (R. H. Speier et al, *Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons*, Rand Corporation, 2017, p. 2, https://www.rand.org/pubs/research_reports/RR2137.html).

8 The CCW's preamble, equally concerned with the prevention of unnecessary suffering, the protection of civilians, the ending of the arms race and disarmament, attests to this. See also, O. Bring, 'Regulating Conventional Weapons in the Future — Humanitarian Law or Arms Control?', 24(3) *Journal of Peace Research* (1987) 275–286; K. Carter, 'New Crimes Against Peace: The Application of International Humanitarian Law Compliance and Enforcement Mechanisms to Arms Control and Disarmament Treaties', The Markland Group and Canadian Council on International Relations (eds), *Treaty Compliance: Some Concerns and Remedies*, Brill/Nijhoff, 1998, pp. 1–21.

9 See, e.g., Article 36, *Directed Energy Weapons*, Discussion Paper, November 2017, http://www.article36.org/wp-content/uploads/2019/06/directed-energy-weapons.pdf

10 For example, the US Navy's SM-6 missiles can not only 'intercept ballistic missiles' but could also be used in an offensive capacity to target enemy ground forces, surface ships and even submarines. See, e.g., D. Axe, 'The SM-6 Is the U.S. Navy's Most Important Missile (It Can Kill Almost Anything)', *The National Interest*, 1 February 2019, https://nationalinterest.org/blog/buzz/sm-6-us-navys-most-important-missile-it-can-kill-almost-anything-42987.

11 'When combined with the benefits of faster C4ISR, enabled by improved processing capabilities and augmented by artificial intelligence, not only will weapons themselves be faster but so too will the capacity to find a target and process all the information necessary to decide whether or not to engage' (International Institute of Strategic Studies, 'The Speed of War: Faster Weapons; Faster Organisations', *Strategic Survey 2018: The Annual Assessment of Geopolitics*, November 2018, Chapter 3, Part IV, https://www.iiss.org/publications/strategic-survey/strategic-survey-2018-the-annual-assessment-of-geopolitics/ss18-04-strategic-policy-issues-4).

12 Zhao opines that '[n]o clear technical distinction can be made between hypersonic missiles and other conventional capabilities that are less prompt, have shorter ranges, and also have the potential to undermine nuclear deterrence' (T. Zhao, 'Going Too Fast: Time to Ban Hypersonic Missile Tests?: A Chinese Response', 71(5) *Bulletin of the Atomic Scientists* (2015) 6).

13 The US was at the forefront of these technology developments and published the results of several of its earlier test programmes including the DARPA Hypersonic Test Vehicle (HTV-2) boost glide, whose test flight ended after just a few seconds. The US Army Advanced Hypersonic Weapon (AHW) and supersonic combustion ramjet (scramjet) programmes also had mixed records of success with the X-51 missile reaching Mach 5 for 210 seconds but only one out of four tests being fully successful. The US Navy HyFly failed to reach hypersonic speed in all tests. Russia has also conducted successful tests of at least two types of hypersonic weapon, the Zircon/Tsirkon and the Avangard, which are reportedly expected to be ready for deployment within the next few years (M. J. Lewis, 'Global Strike Hypersonic Weapons', 1898(1) *AIP Conference Proceedings* (2017), https://doi.org/10.1063/1.5009210; J. M. Acton, 'The Arms Race Goes Hypersonic', *Foreign Policy*, 30 January 2014, https://foreignpolicy.com/2014/01/30/the-arms-race-goes-hypersonic/; Podvig and Stukalin, 'Russia Tests Hypersonic Glide Vehicle'; S. Taheran, 'Putin Sets Hypersonic Deployment Plan', *Arms Control Today*, 8 January 2019, https://www.armscontrol.org/act/2019-01/news-briefs/putin-sets-hypersonic-deployment-plan).

14 Acton, 'Hypersonic Boost-Glide Weapons'; Podvig and Stukalin, 'Russia Tests Hypersonic Glide Vehicle'; L. Saalman, 'China's Calculus on Hypersonic Glide', Commentary, SIPRI, 15 August 2017, https://www.sipri.org/commentary/topical-backgrounder/2017/chinas-calculus-hypersonic-glide. Japan is also reportedly seeking to develop hypersonic weapons, A. Ragge, 'Japan: Plans for Electronic-Warfare and Hypersonic Capabilities', *Military Balance*, 3 December 2018, https://www.iiss.org/blogs/military-balance/2018/12/japan-plans-hypersonic-capabilities.

15 Speier et al, *Hypersonic Missile Nonproliferation*, p. xi.

16 Ibid, pp. 2, 3, 8, 10.

17 Ibid, p. 11. The major part of the trajectory of existing manoeuvring re-entry vehicles (MARVs) is ballistic.

18 Ibid, p. 8.

19 Ibid, pp. xii, 103.

20 Ibid, p. 12.

21 See, e.g., D. Axe, 'Russia's Deadly Iskander-M Ballistic Missile Is Headed to Kaliningrad Exclave', *The National Interest*, 2 January 2019, https://nationalinterest.org/blog/buzz/russias-deadly-iskander-m-ballistic-missile-headed-kaliningrad-exclave-40397.

22 Hypersonic weapons potentially under development include hypersonic bullets (see, e.g., M. Episkopos, 'Russian Snipers Might Soon Have a New Weapon: Hypersonic Bullets', *The National Interest*, 22 November 2018, https://nationalinterest.org/blog/buzz/russian-snipers-might-soon-have-new-weapon-hypersonic-bullets-36807) and hypersonic projectiles for railguns (e.g. Department of the Navy, 'Special Program Announcement for 2012 Office of Naval Research Research Opportunity: "Hyper Velocity Projectile (HVP) Research"', Special Notice 12-SN-0017, 2012, https://www.fbo.gov/index?s=opportunity&mode=form&id=be58c376763c82be08f9dd44f58637ce&tab=core&_cview=0), as well as the use of hypersonic technologies in relation to 'manned and unmanned reusable air vehicles' (Speier et al, *Hypersonic Missile Nonproliferation*, p. 4), and 'fast penetrating intelligence, surveillance, and reconnaissance (ISR) platforms' that could supplement or replace space surveillance or operate as cueing systems for weapons (Lewis, 'Global Strike Hypersonic Weapons', 02005-3.

23 A. F. Woolf, 'Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues', CRS Report for Congress, R41464, April 2018 (updated 8 January 2019), p. 10, http://www.fas.org/sgp/crs/nuke/R41464.pdf.

24 Ibid, p. 17.

25 A. Macias, 'Russia Again Successfully Tests Ship-Based Hypersonic Missile Which Will Likely be Ready for Combat by 2022', CNBC, 20 December 2018, https://www.cnbc.com/2018/12/20/russia-tests-hypersonic-missile-that-could-be-ready-for-war-by-2022.html.

26 Taheran, 'Putin Sets Hypersonic Deployment Plan'.

27 M. Bodner, 'Russia to World: Our New Nukes Are "No Bluff"', Defense News, 12 March 2018, https://www.defensenews.com/industry/techwatch/2018/03/12/russia-to-world-our-new-nukes-are-no-bluff/.

28 Besser et al, 'Hypersonic Vehicles', p. 13.

29 Lewis, 'Global Strike Hypersonic Weapons', p. 020005-2.

30 Once in the atmosphere, hypersonic weapons could change trajectory, marking a significant departure from ballistic missiles, which follow a trajectory determined by physical forces such as gravity and air resistance and are therefore more predictable and interceptable. Together with their much greater speed compared to existing cruise missiles, this makes hypersonic weapons especially difficult to defend against (Speier et al, *Hypersonic Missile Nonproliferation*, p. xii).

31 R. H. Speier, 'Hypersonic Missiles: A New Proliferation Challenge', *The RAND Blog*, 29 March 2018, https://www.rand.org/blog/2018/03/hypersonic-missiles-a-new-proliferation-challenge.html.

32 In 1998, a committee charged with reviewing the US Air Force Hypersonic Technology Program concluded that, except for 'the need to strike time-critical and exceptionally hardened targets', the Air Force had not established operational requirements or assessed whether the hypersonic weapon under development would in fact be the best means to fulfil that need (Committee on Review and Evaluation of the Air Force Hypersonic Technology Program, *National Research Council, Review and Evaluation of the Air Force Hypersonic Technology Program*, The National Academies Press, 1998, p. 13).

33 P. Podvig, 'Blurring the Line Between Nuclear and Nonnuclear Weapons: Increasing the Risk of Accidental Nuclear War?', 72(3) *Bulletin of the Atomic Scientists* (2016) 146; J. M. Acton (ed.), *Entanglement: Chinese and Russian Perspectives on Non-Nuclear Weapons and Nuclear Risks*, Carnegie Endowment for International Peace, 2017.

34 Speier et al, *Hypersonic Missile Nonproliferation*, pp. 13, 18.

35 D. Ghoshal, *Hypersonic Weapons: The New Age Weapon System*, Opinion Document 98/2018, Spanish Institute for Strategic Studies, 27 September 2018, http://www.ieee.es/en/Galerias/fichero/docs_opinion/2018/DIEEEO98-2018_DEBGOS_Hypersonics_eng.pdf; S. Brimley et al, 'Building the Future Force: Guaranteeing American Leadership in a Contested Environment', Center for a New American Security (CNAS), 29 March 2018, https://www.cnas.org/publications/reports/building-the-future-force, p. 26.

36 R. Nagappa, 'Hypersonic Missiles: Where the Technology Leads', 29 July 2015, M. Gubrud, R. Nagappa, T. Zhao, 'Test Ban for Hypersonic Missiles', Roundtable, Round 3, *Bulletin of the Atomic Scientists*, 6 August 2015, https://thebulletin.org/roundtable/test-ban-for-hypersonic-missiles/.

37 Zhao, 'Going Too Fast', 6.

38 Ibid, 2.

39 M. Gubrud, 'The Argument for a Hypersonic Missile Testing Ban', 2 September 2014, *Bulletin of the Atomic Scientists*, https://thebulletin.org/2014/09/the-argument-for-a-hypersonic-missile-testing-ban/.

40 T. Walton, 'Why We Need the Advanced Hypersonic Weapon', *War on the Rocks*, 9 June 2014, https://warontherocks.com/2014/06/why-we-need-advanced-hypersonic-weapon/.

41 In tests, hypersonic cruise missiles have proven difficult to launch, with igniting their engine being compared to 'lighting a match in a 2,000-mile-per-hour wind'. Engineers working on HCMs – which rely on an air-breathing propulsion system – are also struggling to ensure that adequate thrust is provided by scramjet engines for the entire duration of the flight, from subsonic to hypersonic speeds (Speier et al, *Hypersonic Missile Nonproliferation*, pp. 104–105.) Once in flight, maintaining the structural integrity of a hypersonic missile at peak speeds as well as the ability to control and navigate is a challenge, particularly due to to significant kinetic heating, depending on the thermal conductivity of its materials (Besser et al, 'Hypersonic Vehicles', p. 16.)

42 Speier et al, *Hypersonic Missile Nonproliferation*, pp. 106–107.

43 Ibid, p. 14.

44 K. Reif, 'Hypersonic Advances Spark Concern', *Arms Control Today*, January/February 2018, https://www.armscontrol.org/act/2018-01/news/hypersonic-advances-spark-concern. The policy of 'hair-trigger alert' evolved during the Cold War in relation to nuclear weapons, and the concern among US military strategists that a Soviet first strike could compromise the ability of the US to retaliate. Weapons or weapon launch systems on 'hair-trigger' or high alert are generally maintained in a ready-for-launch state.

45 Hypersonic weapons have the potential to 'decapitate a nation's leadership before it has the opportunity to launch a counter attack', R. Speier, 'Hypersonic Missiles'.

46 For example, on 9 August 2019 US Vice President Mike Pence outlined plans to create a Space Operations Force by 2020, citing the existence of Russian and Chinese military operations in space and the potential of 'highly threatening in-orbit activities and evasive hypersonic missiles' ('Pence Says U.S. Aims to Create New Space Force by 2020', Radio Free Europe/Radio Liberty, 24 October 2018, https://www.rferl.org/a/white-house-vice-president-pence-says-aim-create-new-space-force-in-steps-by-2020/29560686.html; E. Durkin, 'Space Force: All You Need to Know About Trump's Bold New Interstellar Plan', *The Guardian*, 10 August 2018, https://www.theguardian.com/us-news/2018/aug/10/space-force-everything-you-need-to-know).

47 Garcia sees the reason for this 'lack of normative alarm' in the attention having shifted 'from weapons systems of interstate strategic consequence to weapons systems of individual consequence,' i.e. from a Cold War arms control paradigm to a humanitarian arms control agenda (O. Garcia, 'No Alarm: Hypersonic Weapons Development and the Shifting Logics of Arms Control', MA Thesis, University of British Columbia, August 2016, 29–30).

48 Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles?'.

49 Egeli deplores that nuclear-armed states 'show little inclination to limit their "post- ballistic" capabilities in weapons of mass destruction (WMD) delivery', which, in turn, provides no incentive to other states to pursue missile control measures (S. Egeli, 'Seeking a Path Toward Missile Nonproliferation', 72(6) *Bulletin of the Atomic Scientists* (2016) 363).

50 For more information, see http://mtcr.info/. On other relevant regimes, see, See *Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control*, UNIDIR and UNODA, 2019, §§ 56-59.

51 Missile Technology Control Regime (MTCR), *Annex Handbook*, 2017, p. 24.

52 Speier et al, *Hypersonic Missile Nonproliferation*, p. 111, who note that 'rocket boosters for HGVs are generally controlled as Category I in the current MTCR Annex. (New to MTCR Annex item 2.A.1.b)'. For more detail, see ibid, pp. 42–45.

53 Speier, 'Hypersonic Missiles'.

54 Bilateral arms control instruments, such as the 1987 Intermediate-Range Nuclear Forces (INF) Treaty would also have the potential to constrain hypersonic weapons, but do not presently apply to them because their definitions do not take account of hypersonic technologies. See, e.g., S. J. Freedberg, 'Army Insists 1,000-Mile

Missiles Won't Breach INF Treaty', *Breaking Defense*, 17 September 2018, https://breakingdefense.com/2018/09/army-insists-1000-mile-missiles-wont-breach-inf-treaty/. Similarly, the New Strategic Arms Reduction Treaty (New START) would not capture warheads deployed on hypersonic glide vehicles (A. F. Woolf, 'Conventional Prompt Global Strike and Long-Range Ballistic Missiles', p. 42).

55 T. Scheber and K. Guthe, 'Conventional Prompt Global Strike: A Fresh Perspective', 32(1) *Comparative Strategy* (2013) 19.

56 Art 2(4), 1945 United Nations Charter; UNGA Res 2625 (XXV), 24 October 1970; UNGA Res 3314 (XXIX), 14 December 1974.

57 Art 36, 1977 Additional Protocol I to the Geneva Conventions (AP I).

58 Arts 48, 51(2) and 52(2), AP I; ICRC Customary IHL Study, Rules 1, 11 and 71.

59 The UN Secretary-General expresses wariness about 'inadequate precision of current guidance systems' (Report of the Secretary-General on current developments in science and technology, §28). Besser et al consider that 'achieving a precise hit will remain very difficult' for HGVs (Besser et al, 'Hypersonic Vehicles', p. 20), and Gubrud warns that hypersonic missiles 'have difficulty using sensors for precise navigation – or to locate and home on mobile targets' (M. Gubrud, 'Hypersonic Missiles: Junk Nobody Needs', 24 July 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 3).

60 International Court of Justice, Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, 8 July 1996, § 105(2)(E).

61 Ghoshal, *Hypersonic Weapons*, p. 16.

62 Gubrud, 'The Argument for a Hypersonic Missile Testing Ban'.

63 M. Gubrud, 'Just Say No', 24 June 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 1.

64 J. Schreiner, 'Hypersonic Weapons Could Create New Arms Race', *Stars and Stripes*, 14 October 2014.

65 J. Aune et al, *Hypersonic Missiles and Arms Control*, Great Plains National Security Education Consortium, n.d., http://www.stratcom.mil/Portals/8/Documents/Hypersonic%20Missiles%20and%20Arms%20Control.pdf?ver=2017-03-31-134237-917.

66 R. Nagappa, 'New Technology, Familiar Risks', 25 June 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 1; T. Zhao, 'Political Obstacles, Technical Tangles', 16 July 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 2.

67 Nagappa believes their support is only likely after they have perfected their hypersonic weapons through testing (R. Nagappa, 'Hypersonics Are Here to Stay', 9 July 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 2).

68 T. Zhao, 'What's Possible: Hypersonic Harm Reduction', 6 August 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles'.

69 Aune et al, Hypersonic Missiles and Arms Control.

70 Podvig, 'Blurring the Line Between Nuclear and Nonnuclear Weapons, 148.

71 Aune et al, *Hypersonic Missiles and Arms Control*.

72 Speier et al, *Hypersonic Missile Nonproliferation*, p. 44.

73 Egeli suggests adding 'hypersonic vehicles' to the 2002 International Code of Conduct against Ballistic Missile Proliferation (Hague Code of Conduct, HCoC), and using it as a basis for a missile test ban (Egeli, 'Seeking a Path Toward Missile Nonproliferation', 363). The politically binding HCoC has 139 subscribing states and aims to prevent and curb the proliferation of ballistic missile systems capable of delivering weapons of mass destruction, and to promote transparency and build confidence. For more information, see https://www.hcoc.at/.

74 Speier et al, *Hypersonic Missile Nonproliferation*, pp. xiv, 45, 110–115.

75 V. Siddhartha, *Spaceplanes, Hypersonic Platforms and the Missile Technology Control Regime*, International Strategic and Security Studies Programme, National Institute of Advanced Studies, Bangalore, 2017, pp. 6–7. Siddharta defines 'Lifting Bodies' or 'Hypersonic Gliders' as 'vehicles capable of return to land or water after traversing the atmosphere from space at speeds of Mach 5 or more, and capable of refurbishment for reuse after such return' (ibid, p. 6).

76 P. van Ham, *The MTCR at 30: Ideas to Strengthen the Missile Technology Control Norm*, Policy Brief, Clindgendael Institute, November 2017, p. 11, https://www.clingendael.org/sites/default/files/2017-11/PB_The_MCTR_at_30.pdf.

77 Speier et al, *Hypersonic Missile Nonproliferation*, p. 48.

78 Siddhartha severely criticizes the report by Speier et al for adopting a 'disdainful, derisive and dismissive attitude to any Indian effort', whilst at the same time arguing that it is 'in India's interest to stymie the self-development by other countries of hypersonic platforms' (Siddhartha, *Spaceplanes*, pp. 2, 6).

79 Zhao, 'What's Possible'.

80 A. Arbatov et al, 'Entanglement as a New Security Threat: A Russian Perspective', Acton, *Entanglement*, p. 40; J. M. Acton, 'A U.S. Perspective on Policy Implications', ibid, p. 83.

81 Although hypersonic glide vehicles had reportedly been raised in bilateral arms reduction talks between the US and Russia, they were expressly omitted from the limits on missile holdings in the New START (Report of the Secretary-General on current developments in science and technology, §41). Hypersonic weapons do not fall within the scope of the INF Treaty because they do not fit its definitions of ballistic and cruise missiles. A hypersonic glide vehicle spends a negligible portion (and not most) of its trajectory in ballistic mode. In December 2018, the US Government announced its intention to suspend the INF Treaty, alleging a material breach by Russia. See *Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control*, §§ 44-45.

82 Nagappa, 'New Technology, Familiar Risks'.

83 Zhao, 'Going Too Fast', 7. See also J. H. Pollack, 'Boost-glide Weapons and US-China Strategic Stability', 22(2) *The Nonproliferation Review* (2015) 161.

84 Work of the Advisory Board on Disarmament Matters, Report of the Secretary-General, UN doc A/71/176, 21 July 2016, §14.

85 UNODA, Securing our Common Future; Work of the Advisory Board on Disarmament Matters, §14.

86 'Pence Says U.S. Aims To Create New Space Force By 2020': 'potential threats in space include … "highly threatening in-orbit activities and evasive hypersonic missiles" … "Space is a war-fighting domain".'

87 *Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control*, §§ 74-75.

NANOWEAPONS

DISCUSSION PAPER FOR THE CONVENTION ON CERTAIN CONVENTIONAL WEAPONS (CCW)

GENEVA, NOVEMBER 2017

Nanomaterials have the potential for significant and diverse impacts on human society.[1] Better energy storage, more rapid computations and lower power consumption are but a few innovations that can lead to considerable improvements in devices and products.[2] Nanomaterials also have potential applications in the military and security sectors. Suggested developments include garments designed to increase soldier survivability[3] and camouflage against thermal detection,[4] as well as new weapons and surveillance technologies.[5]

This bulletin provides an introduction to possible military uses of nanomaterials and suggests some areas of concern, notably:

- Novel or poorly understood mechanisms of harm and new ways of applying force (e.g. using genetic markers as a tool for targeting) may challenge existing values, norms and instruments (e.g. the principle of humanity, the prohibitions on indiscriminate attacks and superfluous injury or unnecessary suffering, or on blinding laser weapons).
- At a conceptual level, certain developments could fall between the boundaries of multilateral weapons control instruments. This is because the use of nanomaterials can challenge the distinctions and categorizations by which regulatory instruments and control regimes are articulated (e.g. between conventional weapons and weapons of mass destruction).
- At a practical level, certain developments may negatively impact disarmament and arms control. For example, nanomaterials or nanodevices (e.g. metal-less firearms, miniaturized weapons) may escape existing verification techniques. This may lead to a loss of trust in the effectiveness of multilateral weapons control regimes in securing international peace and security.

Based on this, the paper recommends that High Contracting Parties to the Convention on Certain Conventional Weapons (CCW):

- monitor developments in nanotechnologies and assess how potential military uses of nanomaterials may challenge existing restrictions or prohibitions on weapons, or impact national and human security, peace and international security, arms control and disarmament;

- examine the how certain effects from nanomaterials should be considered in relation to existing Protocols of the CCW and make national interpretations where appropriate;
- explicitly include reference to nanomaterials in ongoing work, including in relation to weapons reviews in line with Article 36 of Additional Protocol I to the Geneva Conventions, and promote a precautionary approach to risks that such materials may present;
- cooperate with the Biological Weapons Convention (BWC), the Chemical Weapons Convention (CWC) and other relevant bodies, to ensure that nanomaterials are addressed by the legal regime appropriate to their effects;
- foster open dialogue and information exchange about military uses of nanomaterials and their potential impacts.

WHAT ARE NANOMATERIALS?

The prefix 'nano' means one thousand millionth of a metre (1 nm = 10^{-9} m).[6] Nanoparticles occur naturally in the environment, such as in volcanic ash, and in some man-made substances, such as depleted uranium. What is new is the ability to deliberately create, manipulate or modify nanomaterials for specific ends.[7] This is of interest because at nanoscale (below 100 nm)[8] matter exhibits different reactive, optical, electrical and magnetic properties than at macroscale.

Nanomaterials also present profound challenges. Chemical, biological and physical properties merge at nanoscale, making some traditional regulatory distinctions uncertain. Furthermore, some materials are toxic at nanoscale even if their macro counterparts are not.[9] Much has been written over the last decade about the regulation of nanotechnologies in general, but comparably little attention has been paid specifically to military applications and weapons.[10]

This bulletin considers possible applications of nanomaterials for military or security purposes, including weapons and combat systems where one or more parts is manipulated artificially, or causes harmful effects, at nanoscale.

CURRENT STATE OF PLAY

The total global, private and public, investment in nanotechnology research and development has grown rapidly since the early 1990s,[11] but research by the military remains mostly out of the public domain, although some states, including China, Germany, France, India, Israel, the Netherlands, Russia, Sweden, the UK and the USA are publicly investing in nanotechnologies for military purposes.[12]

The literature cites a large array of potential military applications of nanotechnologies, claiming advantages related to better detection and surveillance as well as improved stealth and camouflage, cost- and fuel-efficiency, increased accuracy of weapon delivery and scalability of weapon effects, the greater destructive force of weapons as well as materials better able to withstand force. The bullet points below provide a partial list of some of the developments utilizing properties of nanomaterials (which may be at different stages from concept to development):[13]

- sensors that allow for improved reconnaissance, better sensory capabilities of weapons and munitions,[14] and the detection, reduction and elimination of biological or chemical agents, or trace quantities of explosives;[15]
- pervasive, distributed nanoscale sensor nets with computational and wireless communication abilities ('smart dust'), potentially as components of an autonomous weapon system;[16]
- missiles, artillery projectiles or mortar rounds with reduced mass, greater destructive force, increased penetration capability, tailored energy release, smaller size or improved accuracy;[17]
- lighter and smaller firearms made of nanofibre composites with low or no metal content, and 'self-steering' bullets equipped with optical sensors;[18]
- means of weapon delivery with reduced drag and increased payload and range,[19] nano-enhanced miniaturized munitions, including for UAVs (drones), and nano- and micro-combat robots, enabling swarming;[20]
- improvements in solid-state and electric laser systems, making them mobile and readily deployable as a weapon;[21]
- novel chemicals and biological agents (potentially self-replicating);[22]
- Nano-implants in soldiers, brain-machine interfaces and manipulation of biological processes, for example to reduce fatigue, increase reaction time or alter perceptions, emotions or thoughts.[23]

POSSIBLE ADVERSE EFFECTS AND RISKS

It has been argued that nanotechnologies may offer '[w]hole new classes of accidents and abuses'.[24] Aside from wider social and ethical issues,[25] key military and security concerns regarding the use of nanomaterials include:

- Novel biochemical agents or toxic substances that can be difficult to detect and counter, and enhanced delivery mechanisms, as well further miniaturization, could make the use of biological, chemical or nuclear weapons more feasible.[26] An additional concern relates to the possibility of using genetic markers to target specific groups or individuals.[27]

× Some nano-enhanced technologies may affect strategic stability, for example by giving a distinct advantage to the offence. This may weaken belief in deterrence, raise the risk of escalation and accidental war and lead to an arms race.[28]

× Certain military applications of nanotechnologies can undermine existing control regimes and mechanisms by calling into question categories and boundaries around which regulations are articulated. The use of nanomaterials can challenge legal definitions of prohibited weapons or acts,[29] thresholds based on calibre, quantity, size or weight of an item,[30] the distinction between conventional weapons and weapons of mass destruction, and between ammunition/munitions and their means of delivery.[31] The difficulty of detecting nano-engineered materials and devices (e.g. novel chemical agents or metal-free small arms) challenges transfer and proliferation controls and verification mechanisms.

× Nanoapplications offer the potential for inexpensive, ubiquitous and pervasive surveillance and intrusive methods of data gathering, raising both human and national security concerns.[32]

× Nano-engineered surveillance devices and weapons, potentially in large quantities, would likely be within the reach of individuals or groups (whether commercial or politically organized), due to easy access to raw materials and knowledge, and because there is no need for large production facilities.[33]

Another key concern is that very little is known about the short- and long-term effects of nanomaterials and the possible negative and unintended side effects for humans and the environment.[34] Nanoparticles are able to traverse the gastrointestinal tract and lungs, and cross cell walls and the blood-brain barrier. Their unique characteristics may lead to unusual toxic effects that are different from those seen at a larger scale, and can complicate their detection and removal from human tissue, the air, water or soil.[35] Nanoparticles interacting with cells can disrupt cellular structures and/or processes essential for cell survival and induce DNA damage, which can lead to cancer or genetic abnormalities in reproductive cells.[36] Risks may be gender- or generationally differentiated.[37]

GOVERNANCE AND REGULATION

A number of existing regulatory frameworks constrain military uses of nanomaterials. These include weapon-specific treaties already in place such as the 1925 Geneva Gas Protocol, the 1972 BWC and the 1993 CWC. Together, these instruments ban nanomaterials of known toxic chemicals or biological agents, as well as nano-sized devices designed to deliver them,[38] except where intended for prophylactic, protective or other peaceful purposes.[39] A strong argument can also be made that the legal bans on biological and chemical weapons extend to nanomaterials with novel properties that affect life processes in ways analogous to known toxic chemicals and pathogens.[40] It has also been argued that using nanoparticles whose physical properties or accumulation in the human body injure at the cellular level without biochemical action, or nanorobots that are programmed to do this, may fall foul of the prohibition in international humanitarian law (IHL) on the use of poison and poisoned weapons.[41]

Furthermore, questions have been raised as to whether nanomaterials that are not readily detectable or removable from human tissue are compatible with the letter and spirit of 1980 CCW Protocol I, which prohibits the use of weapons that primarily injure by non-detectable fragments;[42] whether miniaturized missiles and similar explosive projectiles run counter to the prohibition on the use of exploding bullets;[43] whether nano-enhanced lasers raise issues under CCW Protocol IV on blinding laser weapons;[44] whether small armed robots undermine the effectiveness of existing strictures on landmines;[45] and whether a nanodevice that is designed to kill or injure and functions unexpectedly when a person performs an apparently safe act, such as breathing, violates the prohibition on booby traps.[46]

IHL also limits the use of nano-enhanced weapons, means and methods of warfare. Fighters are protected against weapons, means or methods of warfare of a nature to cause superfluous injury or unnecessary suffering or that render death inevitable,[47] as may be the case with nanomaterial-induced health effects. Civilians 'enjoy general protection against dangers arising from military operations',[48] which would include, for example, protection from hazardous nanoparticles released into the environment as a result of the degradation of armour or as components of surveillance networks. They are also protected against attacks employing a method or means of combat whose effects cannot be limited as required by IHL, for example, due to the release of hazardous particles.[49] Precautions must be taken against such effects, including in the choice of weapons and targets, so as to minimize the danger to civilians.[50]

Additional restrictions derive from states' duties under international human rights and environmental law. Everyone is protected, at all times, against discriminatory targeting practices[51] and acts of genocide,[52] which may be facilitated by the ability to target at the DNA level. In light of the release of potentially hazardous nanoparticles during security or military operations, states must take measures to effectively protect the rights to life, health and food.[53]

In this regard, measures to prevent environmental damage, including in armed conflict, will be particularly important. Nanotechnology-enabled surveillance possibilities call for measures by states to protect the right to privacy.[54] States should also anticipate that the difficulty of detecting nanomaterials or nanodevices is likely to exacerbate existing accountability challenges, especially where applications are tested on or used among populations that have limited recourse against their effects.

Given the potential for serious negative consequences, it is widely accepted that a precautionary approach is essential. Views diverge, however, on what that implies in practice. Some argue for a strict application of the 'no data, no market' principle,[55] whereas others promote the development of regulations or meta-regulatory tools to 'help ensure the technology achieves its potential for good'.[56] The public (scientific) debate on potential risks and hazards has, however, largely ignored military uses of nanomaterials. Although states have a legal obligation under IHL to review the compatibility of new weapons, means or methods of warfare with their international legal obligations,[57] such reviews suffer from well-known limitations and lack of implementation. There are also many open questions about their effectiveness when it comes to nano-enhanced weapons, means or methods of warfare.[58]

Many consider, therefore, that prompt action is required to govern the potential risks of nano-enhanced weapons and other military uses of nanomaterials. Proposals include:

× the creation of a new treaty or an arms control regime to devise limits and verification methods;[59]

× amendments to existing instruments, notably the CWC and the BWC, or clarification of their provisions;[60]

× clearer guidance and transparency for weapon reviews;[61]

× and the development of guidelines and scientific protocols to promote self-regulation by states and scientific communities.[62]

NOTES

1 E.g., The Royal Society and The Royal Academy of Engineering, July 2004, 'Nanoscience and Nanotechnologies: Opportunities and Uncertainties', p. 5, https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2004/9693.pdf; M. C. Roco and W. Sims Bainbridge (eds), 'Societal Implications of Nanoscience and Nanotechnology', NSET Workshop Report, National Science Foundation, 2001, p. 3, http://www.wtec.org/loyola/nano/NSET.Societal.Implications/nanosi.pdf. Nanotechnology is not a single industry or discipline, but rather 'sets of enabling technologies applicable to many traditional industries'. It is therefore more appropriate to speak of nanotechnologies (J. Schummer, 'Identifying Ethical Issues of Nanotechnologies', H. A. M. J. ten Have (ed.) *Nanotechnologies, Ethics and Politics*, 2007, p. 87, http://unesdoc.unesco.org/images/0015/001506/150616e.pdf).

2 See, e.g., The Project on Emerging Nanotechnologies, 'Inventories', http://www.nanotechproject.org/inventories.

3 'U.S. Scientists Design Smart Underpants That Could Save Lives', *Reuters*, 10 June 2010, http://uk.reuters.com/article/oukoe-uk-underpants-health/u-s-scientists-design-smart-underpants-that-could-save-lives-idUKTRE6591C920100610.

4 B. Kim et al, 'Patternable PEDOT Nanofilms With Grid Electrodes for Transparent Electrochromic Devices Targeting Thermal Camouflage', 2(1) *Nano Convergence* (October 2015), https://doi.org/10.1186/s40580-015-0051-9.

5 In particular, J. Altmann, *Military Nanotechnology: Potential Applications and Preventive Arms Control*, 2006, Chapter 4.

6 Nanowerk, 'Nanotechnology Frequently Asked Questions', http://www.nanowerk.com/nanotechnology_frequently_asked_questions.php.

7 B. Bhushan, 'Nanotechnology', B. Bhushan (ed.), *Encyclopedia of Nanotechnology*, 2012; K. Leins, 'Regulation of the Use of Nanotechnology in Armed Conflict', IEEE Technology and Society Magazine, n.d.

8 International Organization for Standardization, 'ISO TC 229: Nanotechnologies', https://www.iso.org/committee/381983.html. 'An upper limit of 100 nm is commonly used by general consensus, but there is no scientific evidence to support the appropriateness of this value' (European Commission, Recommendation of 18 October 2011 on the definition of nanomaterial, 2011/696/EU, §8)

9 According to Schummer, 'Identifying Ethical Issues of Nanotechnologies', p. 85, 'national regulations for chemicals, consumer products and work safety disregard the size- and shape-dependence of properties and focus solely on chemical composition. This means that a substance could, for instance, pass the required toxicity tests for new chemicals if the tests are performed on large particles, even if small particles of the same substance are toxic'.

10 There is no agreed definition of a 'nano-(enhanced) weapon'. The term sometimes refers to 'objects and devices using nanotechnology ... that are designed or used for harming humans'. It can also designate devices that cause harmful effects in nanoscale, though some scholars limit the category to those whose 'effects characterise the lethality of the weapon' (H. Nasu and T. Faunce, 'Nanotechnology and the International Law of Weaponry: Towards International Regulation of Nano-Weapons', 20 *Journal of Law, Information & Science* (2009–2010) 21, 23.

11 Several indicators can be used to assess research and development in nanotechnologies, for example, the number of patent filings, the development of sub-areas or the number of citations. See, e.g., M. C. Roco et al (eds), *Nanotechnology Research Directions for Societal Needs in 2020: Retrospective and Outlook*, 2010, pp. xlii–xlvi, http://www.wtec.org/nano2/Nanotechnology_Research_

Directions_to_2020/Nano_Resarch_Directions_to_2020.pdf. For data, see OECD, 'Tapping Nanotechnology's Potential to Shape the Next Production Revolution', OECD, *The Next Production Revolution: Implications for Governments and Business*, 2017.

12 For a recent overview, see J. Altmann, 'Preventing Hostile and Malevolent Use of Nanotechnology: Military Nanotechnology After 15 Years of the US National Nanotechnology Initiative', M. Martellini and A. Malizia, *Cyber and Chemical, Biological, Radiological, Nuclear, Explosives Challenges: Threats and Counter Efforts*, 2017), pp. 52–56. See also A. de Neve, 'Military Uses of Nanotechnology and Converging Technologies: Trends and Future Impacts', Center for Security and Defence Studies, Royal High Institute for Defense, Focus Paper 8, n.d., https://www.yumpu.com/en/document/view/23516906/military-uses-of-nanotechnology-and-converging-technologies-; M. Berger, 'Military Nanotechnology – How Worried Should We Be?', Nanowerk, 13 November 2006, https://www.nanowerk.com/spotlight/spotid=1015.php.

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14 H. Paschen et al, *Nanotechnology: Summary*, Working Report no 92, Office of Technology Assessment at the German Bundestag July 2003, p. 7, https://www.tab-beim-bundestag.de/en/pdf/publications/summarys/TAB-Arbeitsbericht-ab092_Z.pdf.

15 N. Pala and A. N. Abbas, 'Terahertz Technology for Nano Applications', B. Bhushan (ed.) *Encyclopedia of Nanotechnology*, 2016, 4070; M. Sadeghi et al, 'Decontamination of Chemical Warfare Sulfur Mustard Agent Simulant by ZnO Nanoparticles', 6(3) *International Nano Letters* (1 September 2016), https://link.springer.com/content/pdf/10.1007%2Fs40089-016-0183-x.pdf.

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17 E.g., J. Altmann and M. Gubrud, 'Anticipating Military Nanotechnology', *IEEE Technology and Society Magazine*, Winter 2004; Paschen et al, Nanotechnology: Summary; 'US Air Force Invests in Western New York Technology; Grants NanoDynamics™ Contract for Nanostructured Tantalum', Nano Tsunami, 29 August 2005, http://www.voyle.net/Nano%20Defence%202005/Defence%202005-0012.htm.

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19 E.g., A. Lang et al, 'Shark Skin Drag Reduction', B. Bhushan (ed.), *Encyclopedia of Nanotechnology*, 2016), 3639.

20 Altmann, Military *Nanotechnology*, pp. 93–95; Altmann and Gubrud, 'Anticipating Military Nanotechnology', p. 36. On nanorobotics, generally, see S. Tsuda, 'Nanorobotics', B. Bhushan (ed.), *Encyclopedia of Nanotechnology*, 2016.

21 H. Nasu, 'The Future of Nanotechnology in Warfare', *The Global Journal*, 4 July 2013, http://www.theglobaljournal.net/article/view/1132/.

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23 J. Thorpe et al, 'Maintaining Military Dominance in the Future Operating Environment: A Case for Emerging Human Enhancement Technologies That Contribute to Soldier Resilience', Small Wars Journal, 13 July 2017, http://smallwarsjournal.com/jrnl/art/maintaining-military-dominance-in-the-future-operating-environment-a-case-for-emerging-huma; K. Leins, 'Shining a Regulatory Spotlight on New Lasers: Regulation of the Use of Nanolaser Technologies in Armed Conflict', 56 *Jurimetrics* (Spring 2016) 266–68; P. Tucker, 'A Breakthrough in the Checkered History of Brain Hacking', *Defense One*, 1 July 2014, http://www.defenseone.com/technology/2014/07/breakthrough-checkered-history-military-brain-hacking/87709/.

24 The Royal Society and The Royal Academy of Engineering, 'Nanoscience and Nanotechnologies', §28.

25 There is concern that advances in nanotechnologies will exacerbate existing biases and inequalities and 'precipitate a redefinition of the concepts of normalcy, disability, health, and disease, and may challenge the very concept of human dignity' (International Bioethics Committee (IBC), Report of the IBC on the Principle of Non-Discrimination and Non-Stigmatization, 3 June 2014, p. 25, http://unesdoc.unesco.org/images/0022/002211/221196e.pdf).

26 Altmann, *Military Nanotechnology*, pp. 101–103; 'Nanotechnology Paves Way for New Weapons', Jane's Chem-Bio Web, 27 July 2005, http://www.hartford-hwp.com/archives/27a/317.html; Kosal, 'Anticipating the Biological Proliferation Threat of Nanotechnology; A. Gsponer, 'From the Lab to the Battlefield? Nanotechnology and Fourth-Generation Nuclear Weapons', 67 *Disarmament Diplomacy*, (October–November 2002), http://www.acronym.org.uk/old/archive/dd/dd67/67op1.htm.

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28 Altmann and Gubrud, 'Anticipating Military Nanotechnology', p. 38; M. E. Kosal, 'Military Applications of Nanotechnology: Implications for Strategic Security I', PASCC Final Report, p. 65, https://www.hsdl.org/?view&did=767053.

29 Nanomaterials can be used to induce changes in the human body that challenge the bans on blinding laser weapons, biological and chemical weapons. See, e.g., Leins, 'Shining a Regulatory Spotlight on New Lasers'.

30 Consider, e.g., the definitions of conventional armaments and equipment in the 1990 Conventional Forces in Europe (CFE) Treaty, the weight-based definition of prohibited explosive projectiles in the 1868 St Petersburg Declaration or weight restrictions on the production of scheduled chemicals in the CWC. See Altmann and Gubrud, 'Anticipating Military Nanotechnology', p. 36.

31 See, e.g., M. Bolton and W. Zwijnenburg, *Futureproofing Is Never Complete: Ensuring the Arms Trade Treaty Keeps Pace with New Weapons Technology*, International Committee for Robot Arms Control (ICRAC) working paper, October 2013, p. 4.

32 J. van den Hoven and P. E. Vermaas, 'Nano-Technology and Privacy: On Continuous Surveillance Outside the Panopticon', 32(3) *Journal of Medicine and Philosophy* (2007).

33 The Royal Society and The Royal Academy of Engineering, 'Nanoscience and Nanotechnologies', §28.

34 M. Schillmeier, 'What ELSA/I Makes Big and Small in Nanotechnology Research', B. Rappert and B. Balmer (eds), *Absence in Science, Security and Policy*, n.d., p. 63.

35 IBC, Report of the IBC on the Principle of Non-Discrimination and Non-Stigmatization, 25.

36 N.A. Lewinski, 'Nanoparticle Cytotoxicity', B. Bhushan (ed.) *Encyclopedia of Nanotechnology*, 2016; F. Nesslany and L. Benameur, 'Genotoxicity of Nanoparticles', B. Bhushan (ed.), *Encyclopedia of Nanotechnology*, 2016.

37 There is emerging evidence on selective placental transfer of nanoparticles, raising concerns over maternal and fetal health (A. K. Vidanapathirana, 'Use of Nanotechnology in Pregnancy', B. Bhushan (ed.), *Encyclopedia of Nanotechnology*, 2016), and it has been argued that '[c]hildren are more vulnerable because their bodies and organs are not fully developed and their body mass is smaller, allowing for greater absorption of toxic substances and lifelong damaging effects' (Women in Europe for a Common Future (WECF), *Nano – The Great Unknown*, Position Paper, February 2012, p. 2, http://www.wecf.eu/download/2012/April/WECF_NanoPositionPaper.pdf.

38 E. J. Wallach, 'A Tiny Problem with Huge Implications – Nanotech Agents as Enablers or Substitutes for Banned Chemical Weapons: Is a New Treaty Needed?', 33(3) *Fordham International Law Journal* (2009) 860–861.

39 R. D. Pinson, 'Is Nanotechnology Prohibited by the Biological and Chemical Weapons Conventions?', 22(2) *Berkeley Journal of International Law* (2004) 304, argues that nanotechnology uses that closely resemble chemical weapons may fall under these exceptions.

40 For a detailed discussion, see Wallach, 'A Tiny Problem with Huge Implications', who also raises the question of whether the CWC and the BWC prohibit the development and use of engineered viruses or nanorobots.

41 International Committee of the Red Cross (ICRC), Customary IHL study, Rules 72, 73 and 74. The dominant interpretation is that the prohibition on poisonous weapons applies only if poisoning is an 'intended' (as opposed to an incidental or accidental) injury mechanism of the weapon. See, Liivoja et al, 'Emerging Technologies of Warfare', p. 619.

42 1980 CCW Protocol I. A recent Danish military manual (Militærmanual om folkeret for danske vaebnede styrker i internationale militaere operationer, 2016, section 3.10) mentions nanotechnology in relation to that prohibition. For a discussion, see Nasu and Faunce, 'Nanotechnology and the International Law of Weaponry', 22. Note, however, that some states consider that the prohibited weapons are only those whose 'primary effect' is to injure by non-detectable fragments. It is also questionable whether nanoparticles can be likened to 'fragments'. In the view of the ICRC, weapons that contain plastic, for example, as part of their design, are not illegal if the plastic is not part of the primary injuring mechanism (ICRC, Customary IHL study, Rule 79).

43 1868 St Petersburg Declaration; ICRC, Customary IHL study, Rule 78.

44 1995 CCW Protocol IV; ICRC, Customary IHL study, Rule 86.

45 1996 Revised CCW Protocol II, 1997 Anti-Personnel Mine Ban Convention; See Altmann, 'Preventing Hostile and Malevolent Use of Nanotechnology', p. 64.

46 1996 Revised CCW Protocol II; ICRC, Customary IHL study, Rule 80. See Wallach, 'A Tiny Problem with Huge Implications', 934.

47 ICRC, Customary IHL study, Rules 70 and 72. Some states consider that a balance must be struck between military necessity and the expected injury or suffering inflicted on a person, and that only excessive injury or suffering violates the prohibition of weapons that are 'of a nature to cause superfluous injury or unnecessary suffering'.

48 Art 51(1), Additional Protocol I to the Geneva Conventions (API); See also ICRC, Customary IHL study, Rule 15.

49 Art 51(4), API; ICRC, Customary IHL study, Rules 1, 17, 71.

50 Art 57(2)(a)(ii) and (3), API; ICRC, Customary IHL study, Rules 15, 17, 18, 19 and 21.

51 Art 26, International Covenant on Civil and Political Rights (ICCPR); Art 2, Convention on the Elimination of All Forms of Discrimination Against Women; Art 2, Convention on the Elimination of Racial Discrimination; Art 6, Universal Declaration on the Human Genome and Human Rights; Art 11, Council of Europe Convention on Human Rights and Biomedicine.

52 Art 1, 1949 Convention on the Prevention and Punishment of the Crime of Genocide.

53 Art 6, ICCPR; Arts 11 and 12, International Covenant on Economic, Social and Cultural Rights.

54 Art 17, ICCPR.

55 WECF, *Nano – The Great Unknown*, p. 3.

56 Responsible Nanotechnologies Code Working Group, *Information on the Responsible Nano Code Initiative*, May 2008. See also Swiss Federal Office of Public Health, Precautionary Matrix for Synthetic Nanomaterials, version 3.0, 2013; European Commission, Commission recommendation on a code of conduct for responsible nanosciences and nanotechnologies research & Council conclusions on responsible nanosciences and nanotechnologies research, 2009, https://ec.europa.eu/research/science-society/document_library/pdf_06/nanocode-apr09_en.pdf;

57 Art 36, API.

58 E.g., how are potential risks and hazards to be assessed, and judgements made about their acceptability, given that the harm mechanisms of nanomaterials are poorly understood, there are no internationally harmonized measurement methods, there is high uncertainty about how to test biocompatibility and appropriately model environmental impacts, and there is significant controversy about whether existing hazard and risk-assessment tools adequately account for the specific properties of nanomaterials? See, e.g., T. Seager et al., 'Why Life Cycle Assessment Does Not Work for Synthetic Biology', 51(11) *Environmental Science & Technology*, 15 May 2017, https://doi.org/10.1021/acs.est.7b01604.

59 E.g., Altmann makes detailed recommendations for preventive arms control (J. Altmann, *Nanotechnology and Preventive Arms Control*, Deutsche Stiftung Friedensforschung, 2005, https://www.ssoar.info/ssoar/bitstream/handle/document/26027/ssoar-2005-altmann-nanotechnology_and_preventive_arms_control.pdf?sequence=1); Wheelis invites consideration of 'a new convention that would prohibit the nonconsensual manipulation of human physiology' (Wheelis, 'Will the New Biology Lead to New Weapons?'); Howard sketches out an 'Inner Space Treaty' (S. Howard, 'Nanotechnology and Mass Destruction: The Need for an Inner Space Treaty', 65 *Disarmament Diplomacy* (August 2002), http://www.acronym.org.uk/old/archive/dd/dd65/65op1.htm.); See also Pinson, 'Is Nanotechnology Prohibited by the Biological and Chemical Weapons Conventions?'

60 E.g., Wallach, 'A Tiny Problem with Huge Implications', 861, 954.

61 E.g., Nasu and Faunce, 'Nanotechnology and the International Law of Weaponry', 54.

62 E.g., ibid.

SWARMS

DISCUSSION PAPER FOR THE CONVENTION ON CERTAIN CONVENTIONAL WEAPONS (CCW)

GENEVA, MARCH 2019

On 28 March 2019, the UK Government announced the awarding of 2.5 million GBP for the development of 'swarm squadrons of network enabled drones capable of confusing and overwhelming enemy air defences'.[1] Such swarms exhibit autonomous behaviour and are pursued by several states, including to attack targets. The prospect of 'essentially unlimited numbers' of weaponized mini-drones has raised fears of 'scalable weapons of mass destruction'.[2] The UK's announcement thus lent a sense of renewed urgency to ongoing deliberations on 'lethal autonomous weapons systems' in the framework of the Convention on Certain Conventional Weapons (CCW), especially as the UK continues to oppose legal restrictions on autonomous weapons in that forum.[3]

Inspired by swarms of insects, flocks of birds and shoals of fish, 'swarming' as a military tactic can be traced back centuries.[4] More recently, technological advances have enabled the pursuit of swarms in the form of networked, mobile, autonomous munitions or robots (including unmanned naval, ground or aerial vehicles (UAVs), also called 'drones'). Such swarms, composed of dozens, hundreds or thousands of potentially very small units could find applications in policing, counter-piracy, port security and similar operations.[5] But this bulletin focuses on their potential applications in a military context, where swarms could fulfil a range of missions, in offensive, defensive and supporting roles.[6]

Defence analysts see the benefits of swarms mainly in their capacity to overwhelm enemy capabilities by their sheer numbers, as well as in their functioning as coordinated, distributed, autonomous systems. Proponents argue that they would 'bring greater mass, coordination, intelligence and speed to the battlefield'.[7] To realize this vision of swarm warfare, they propose new paradigms of military organization and command and control. Among other issues, swarms thus raise questions about the quality of human control over the use of weapons and their effects – questions that intersect with the ongoing debates on autonomous weapons and on armed drones.

This bulletin briefly summarizes reported military advances in swarming technologies as well as recent policy commentary on the topic. It flags potential risks from the perspective of international and human security and disarmament, and suggests some areas of concern. Some of these are relevant to the CCW, a 'hybrid treaty' that sits at the intersection of arms control, disarmament and humanitarian law:[8]

- Swarms implicated in the detection, selection and attack of targets raise acute questions about human control over the use of force, as well as pressing legal, ethical, security and other concerns at the centre of the debate on 'lethal autonomous weapons'. The emergent behaviour of swarms and the proposition that a single operator could control a potentially large swarm heightens these concerns.
- Swarms risk entrenching problems posed by the use of armed drones in present practice, including the expansion of armed force, patterns of humanitarian harm and challenges to the international rule of law.
- Swarms could take different forms that may not fit well into existing legal categories, creating uncertainty about the legal ramifications of their use. To prevent swarm development from eroding long-standing legal protections, states must reaffirm the central values enshrined in existing law and actively seek to clarify the legal and ethical boundaries in swarm development: agreed legal standards constraining autonomous weapons and armed drones are needed.
- Ongoing multilateral efforts aimed at the control of (armed) drones and autonomous weapons should attend to concerns raised by the prospect of swarms. They should also be attentive to how visions of swarm warfare may be drawn upon to undercut weapons control efforts in other areas.

CURRENT STATE OF PLAY

As a military concept, swarming – converging on a target from different directions simultaneously, either with fire or in force – has a long history.[9] In recent years, some military analysts have argued for swarming to be recognized as a 'doctrine in its own right'.[10] Contemporary visions of swarm warfare draw on networked military forms of organization and technological advances, notably in the fields of information technologies, robotic systems, sensor networks and artificial intelligence. Central to this idea is the deployment of myriad, small, mobile, dispersed, autonomous units that are interconnected.[11] From a US vantage point, the recent emphasis on swarms following a period of heavy reliance on high-tech, precision-strike, stand-off capabilities, is often explained as a way of countering adversaries' increasing capacity to deny US forces access to and restrict movement within an area (anti-access, area-denial, A2/AD).[12]

Several militaries are working towards distributed, collaborative systems of interconnected robots that can move and act as an integrated entity capable of performing autonomously with only limited human intervention.[13] Such projects aim to harness the power of swarm intelligence – the collective, global behaviour that emerges from the local interactions (sensing, communication, etc.) among decentralized and self-organized units and between these units and their environment.[14] The units in a swarm cooperate to achieve a global task but operate without centralized control or global knowledge.[15] Even when the interactions of swarm units are governed by simple control rules, the swarm as a whole can exhibit complex, emergent behaviours.[16]

In contrast to present-day remotely piloted, larger drones, swarming drones would be highly autonomous, flying themselves and coordinating their actions to avoid collisions and maintain swarm cohesion.[17] One human operator could control an entire swarm as a single entity. According to Paul Scharre, '[h]uman commanders will need to control swarms at the mission level, giving overarching guidance, but delegating a wide range of tasks to autonomous systems'. He argues for a shift of human control to the swarm as a whole, respectively, to the mission level,[18] and explores several possible command and control models.[19]

Swarms could be composed of identical units or incorporate units of different types and sizes. These can, for example, consist of rotary or fixed-wing UAVs, which could also collaborate with maritime or ground drones, as well as with manned platforms. Such drones could carry various payloads including jammers for electronic warfare, sensors, tear gas or explosive warheads. They could be reusable (yet expendable) or single-use. In a use of force context, swarms could serve as 'multiple unmanned platforms and/or weapons deployed to accomplish a shared objective'.[20] The number of units in a swarm may vary, depending on its purpose. In current tests, swarms have incorporated from a couple to over 1000 units, but size could potentially extend further.

Analysts are discussing numerous potential applications of swarms in naval, air and land warfare, independently and in cooperation with other weapons systems. These include the following:

- Swarms could 'act as agile mines to protect perimeters around military assets'.[21] They also could serve to 'conduct ... a siege by targeting all vehicular traffic into or out of a populated area'.[22]
- Swarms could 'disperse over large areas to identify and eliminate hostile surface-to-air missiles and other air defenses',[23] assist in maritime interception or search for enemy submarines, aircraft carriers, fighter jets or other high-value targets, and launch 'saturation assaults' to overwhelm[24] or 'confuse, deceive or wear down enemy defences'.[25]
- Swarms could blanket an area with multiple sensors[26] and be used for intelligence-gathering, surveillance and reconnaissance.[27] They could even be used to explore buildings and locate enemy combatants or civilians in 'cluttered and adversarial environments'.[28]

- There could also be a role for swarms in acting as decoys with the aim of disorienting and disrupting attacking forces or confusing or jamming enemy radars, or to infiltrate command networks to perform cyberattacks.[29]
- Explosive ordnance detection and disposal, as well as medical assistance and logistics resupply are also envisaged.[30]

Militaries expect a number of potential benefits from swarms. According to NATO, 'swarms are scalable, tasks can be accomplished more quickly and they allow access to a broader set of sensors and tools'.[31] By sheer force of numbers, swarms offer the potential to 'saturate and overwhelm' enemy defences when focused against a single target or a few, or alternatively, disperse[32] to 'expand the total number of targets that a sortie could successfully take out'.[33] Their numbers also mean that some units could be expendable, thus able to 'serve as decoys, soaking up defensive fires and distracting attention from other swarm components'.[34] Expendability depends somewhat on their cost, however, a point on which analysts' expectations diverge.[35] By acting collaboratively – particularly in different functions such as electronic attacks, decoys and jamming alongside kinetic strikes[36] – proponents hope that swarms could 'outsmart' enemy forces. Whereas some commentators highlight that swarms would be relatively 'robust to failure', due to their lack of a 'critical command unit',[37] others warn that swarms may be be particularly vulnerable to electronic interference due to the need of swarms units to communicate with each other.[38]

Though swarms have not yet been deployed in operations, they have attracted significant investment, research and development in a number of states. Considerable hurdles remain, however, before swarms could be viably fielded. Real-life conditions such as weather and wind turbulence, as well as the difficulties of long-range communication, can affect the performance of swarms, and questions remain over the stability of larger or high-velocity swarms.[39] Despite technological advances, developing cost-effective means with the speed, agility and range necessary for utility in combat operations remains a challenge. There are also unresolved conceptual and doctrinal issues,[40] and there is resistance to unmanned platforms in some quarters due to the (financial) resources their development and maintenance diverts from manned systems, and because of deeper-ingrained cultural attitudes of military personnel.[41]

In spite of these hurdles and the difficulty of determining the precise pace and extent of technological developments due to military secrecy, it appears from open-source material that several states have made significant strides towards developing swarms of varying sizes. The UN Secretary-General warned in a recent report that 'the widespread availability of [sophisticated remotely-piloted aerial vehicles] with swarming or other autonomous functions is plausible in the short term':[42]

- The US is thought to have been investigating the possibility of drone swarms for over a decade.[43] In 2018, the US Office of Naval Research awarded a contract of nearly USD 30 million to Raytheon, a major defence contractor, for the development of swarming UAVs as part of its LOCUST (Low-Cost UAV Swarming Technology) programme.[44] This followed the successful in-flight deployment in 2016 of a swarm of 103 Perdix micro-drones[45] that 'displayed collective decision making, adaptive formation flight, and self healing'.[46] The US Defense Advanced Research Projects Agency (DARPA) has also been furthering its 'Gremlins' programme, which 'seeks to show the feasibility of conducting safe, reliable operations involving multiple air-launched, air-recoverable unmanned systems', which will have 'coordinated, distributed capabilities'.[47] In 2017, DARPA announced that its Collaborative Operations in Denied Environment (CODE) project had demonstrated swarm abilities to 'adapt and respond to unexpected threats' and that their drones had 'efficiently shared information, cooperatively planned and allocated mission objectives, made coordinated tactical decisions, and collaboratively reacted to a dynamic, high-threat environment with minimal communication'.[48] The US Office of Naval Research CARACaS (Control Architecture for Robotic Agent Command and Sensing) project has also shown progress towards collective autonomy used for perimeter surveillance and protection. In 2016, a 13-boat swarm with 1 human operator demonstrated the ability to 'identify, surround and harass an enemy vessel with little human supervision'.[49]
- China, the leading manufacturer of small consumer drones, has had significant successes in swarming technologies. In 2017, it demonstrated the ability to launch the largest swarm to date – 1,108 individual drones, which appeared to operate with high levels of autonomy and reportedly have the ability to self-repair.[50] Though no official figures are publicly available, China is thought to be investing heavily in AI research and development, and the Chinese Academy of Sciences is currently drafting the Artificial Intelligence 2.0 Plan, which is expected to cover 'big data, intelligent sensing, cognitive computing, machine learning and swarm intelligence'.[51]
- The European Union and a number of individual European states have also dedicated research to the potential of swarms. The EU's efforts include the EuroSWARM project funded by the European Defence Agency, under which researchers aim to 'test and demonstrate the efficient and effective operation of unmanned swarm systems'.[52] The UK's Defence Science and Technology Laboratory has for nearly a decade funded

research and development projects related to autonomy, including swarming and autonomous navigation for unmanned systems.[53] In February 2019, the UK's Defence Secretary announced funding to 'develop swarm squadrons of network enabled drones capable of confusing and overwhelming enemy air defences'.[54] France and Germany have awarded a €65 million contract to Dassault and Airbus for a two-year study to progress their Future Combat Air System (FCAS) programme, which envisages the development of a network of swarming UAVs as well as next-generation aircraft and other weapons.[55]

- According to David Hambling, the Republic of Korea, Israel, Turkey and Russia are all also working on swarming capabilities.[56]

Swarming technology has thus far been demonstrated in limited ways in controlled spaces, and has not been tested in complex, challenging and rapidly shifting environments as could be expected in combat or other operational situations. Nevertheless, DARPA has begun research to allow for micro-drone swarm operations within urban environments and built-up areas.[57] Plans exist for the use of swarms of explosive munitions in 'contested environments'.[58] The 'swarm attacks' with explosives-carrying drones by non-state armed groups that made headlines last year,[59] however, did not involve 'swarms' as understood in this paper, as the drones lacked the required inter-drone coordination, communication and self-organization.

ADVERSE EFFECTS AND RISKS

Swarms pose a host of questions and concerns, some of which are also discussed in relation to autonomous weapons and armed drones. Key issues include the following:

- Like other autonomous systems, swarms raise questions about the quality and appropriate form of human control. Because there is no universal model for understanding what emergent behaviours will arise from simple rules,[60] it is questionable whether a person in charge of a swarm is able to sufficiently predict its behaviour to make the required ethical and legal assessments and be responsible for it.[61] In the context of an armed conflict, this lack of predictability poses a challenge to the protection of civilians against dangers arising from military operations.[62] These concerns are accentuated if swarms are to be used in populated areas and inside buildings.

- Insofar as swarms partake in attacks (as defined under international humanitarian law), for example by detecting, selecting or applying force to targets, their use raises pressing ethical, legal and other concerns.[63] At an Informal Meeting of Experts on Lethal Autonomous Weapons Systems (LAWS) held in 2016, the view was expressed that swarms 'would be inherently unpredictable',[64] and that this unpredictability could be 'exacerbated in situations where multiple systems or swarms of systems interact'.[65] In such situations, experts argued, 'it would be unclear how meaningful human control could be maintained over the use of force'.[66]

- In addition, the prospect of a single human operator commanding an entire swarm consisting of potentially large numbers of units[67] raises concern about the 'cognitive load' placed on individual operators.[68] Urgent questions may arise about the health and human rights of military personnel and others tasked with the control of such systems.[69]

- As with other advanced weapons systems, there is a concern that swarms could be vulnerable to spoofing, manipulation, hijacking and other electronic warfare attacks. The risk of such interferences may be elevated for swarms, compared to other modern weapons systems, due to their high degree of autonomy.[70]

- Swarms could also aggravate existing challenges raised by the use of armed UAVs in present practice, notably in terms of harm caused to individuals and communities and the lack of transparency, oversight and accountability surrounding their use.[71] Swarms (of drones or munitions) could increase the potential for misuse, undermine legal protections under international humanitarian and human rights law, promote controversial surveillance and mass data collection,[72] further expand the use of armed force and erode the international rule of law.[73]

- Swarms may also pose challenges to international peace, security and stability. Analysts have warned that increasing autonomy and the accelerated pace of swarms could be 'exceptionally dangerous and destabilizing', lead to 'flash wars'[74] and increase conflict instability. There is also a concern that swarms may induce a shift in the 'offense-defense balance' that drives a destabilizing and costly arms race[75] and, by favouring the offensive, incentivizes pre-emptive first strikes that would place additional strain on the international rules for the maintenance of peace and security.[76] Finally, commentators have warned that swarm technologies would proliferate quickly,[77] and that swarms of armed micro-drones would also be accessible to non-state groups and individuals who could produce them with widely available technologies.[78]

- Swarms, respectively their units, may not fit neatly into existing regulatory categories. This creates legal uncertainty and controversy[79] and raises questions about the capacity of existing law, as applied in practice, to govern the development of swarms while upholding the values that the law was made to protect. Hambling points out that some small UAVs are 'designed as payload-carriers which could be fitted with a range of options on a mission-by-mission basis, while also being capable of being deployed to strike a target directly with a fixed explosive, making the distinction between UAVs and loitering munitions an arbitrary one'.[80] In the context of arms transfer controls, Matthew Bolton and Wim Zwijnenburg have raised questions about the legal categorization of small drones, asking whether the 'Switchblade' (often mentioned in relation to future swarms), which is described by the manufacturer as a 'miniature flying lethal missile' that 'can be operated manually or autonomously'[81] should be considered a 'combat aircraft', a 'missile' or a 'munition' for the purposes of the UN Register of Conventional Arms and the 2013 Arms Trade Treaty.[82] Questions about legal categories also arise in the context of international law applicable to air and missile warfare,[83] and considerable uncertainty persists in this regard in the area of maritime law and naval warfare, creating controversy about the legal ramifications of their use.[84]

- Another concern relates to the promise of swarms to bring 'mass' back to the battlefield,[85] with some analysts envisaging the deployment of 'billions – yes, billions – of tiny, insect-like drones'.[86] The prospect of 'saturating' territory with high numbers of small explosive devices, 'mining the airspace' and 'flooding' zones and buildings so that they are 'seemingly, everywhere and nowhere at once'[87] is alarmingly reminiscent of past practices that inspired legal prohibitions on area bombardment, cluster munitions and landmines due to their unacceptable humanitarian consequences.[88] Indeed, plans exist to develop 'a cluster payload', which can be launched from a guided multiple-launch rocket system and would 'consist of multiple deployable smart quad-copters capable of delivering small explosively formed penetrators (EFP) to designated targets'.[89] The 2008 Convention on Cluster Munitions places some restrictions on such developments, but many swarms may not fall within its purview.[90]

- As a consequence of the renewed enthusiasm for 'mass' and 'saturation', concern has arisen that swarms of explosive micro-drones could pose a post-conflict risk to civilians when they fail to explode as intended and become explosive remnants of war (ERW).[91] This risk is exacerbated if swarms are used in densely populated areas and inside buildings.[92] Children could be at a particular risk of harm from micro-drones resembling toys,[93] as has been the case with certain anti-personnel mines and cluster submunitions. Insofar as swarm units fit the definition of 'explosive ordnance', the 2003 Protocol V to the CCW and its Technical Annex set out responsibilities regarding the prevention, recording, clearance, removal and destruction of ERW and require precautionary measures for the protection of civilians. Maziar Homayounnejad points out that if swarm units can be likened to (remotely delivered) 'mines', the stricter standards (on recording for example) of the 1996 revised Protocol II to the CCW would apply.[94]

- Rather than being associated with cluster munitions, saturation bombardments and minefields, however, swarms are more commonly envisioned as enabling 'mass-*precision* attacks',[95] with proponents drawing inspiration from contemporary 'targeted killings' carried out with UAVs. This orientation raises concern about the normalization of what is, from a legal and ethical standpoint, a highly controversial practice.[96] Similarly, scenarios of 'slaughterbots'[97] – small, expendable, explosive weapons deployed in swarms to attack individual people – elaborated by opponents of autonomous weapons, call into question the long-standing legal protection of combatants against exploding projectiles and assumptions about what constitutes superfluous injury or unnecessary suffering.[98] Even commentators dismissing 'slaughterbots' as fanciful fail to acknowledge the transgression of established norms implied in these and similar swarm scenarios.[99]

GOVERNANCE AND REGULATION

Although swarms are clearly on the list of technologies militaries see on the horizon,[100] they have not, thus far, attracted focused attention in multilateral weapons control fora.[101] The UN Secretary-General's report on current developments in science and technology and their potential impact on international security and disarmament efforts mentions that '[g]roups of networked unmanned vehicles can act as swarms'[102] but does not expand further.

Scharre considers that many of the issues swarms raise 'can be addressed through better technology, concepts of operation or training'.[103] These include, for example, measures to ensure that a sufficient number of operators are available to command a swarm, as well as suitably designed interfaces, training to understand the behaviour and limits of swarm automation in real-world environments, as well as the modification of doctrine and organizational structures.[104]

Other commentators see value in multilateral governance measures, including regulations on swarms. Homayounnejad outlines how a range of technical measures, including design stipulations to prevent civilian harm from ERW caused by swarms of explosive munitions or micro-drones, can be introduced either by applying CCW Protocol V, the Convention on Cluster Munitions and/or instruments on landmines directly to swarms, or by drawing on these treaties to elaborate swarm-specific standards and criteria in national or international instruments. Such standards could limit the size of swarms.[105] They could also aim to prevent explosive drones of toy-like appearance, set thresholds for reliability and detectability and specify required technical measures to reduce the risk of ERW and facilitate the location of ERW and their safe clearance. Homayounnejad concedes, however, that technical measures may run against the underpinning logic of creating huge numbers of explosive drones at a low cost.[106]

Efforts aimed at the control of armed drones and autonomous weapons also have a bearing on swarms.[107] These are extensively discussed elsewhere and are only dealt with in a cursory manner here:

- In the framework of the CCW, a Group of Governmental Experts currently debates 'possible options for addressing the humanitarian and international security challenges posed by emerging technologies in the area of lethal autonomous weapons systems'.[108] At the core of the debate is the imperative to ensure human control and accountability in the use force.[109] Options under consideration include the negotiation of a legally binding instrument stipulating prohibitions or regulations on 'lethal autonomous weapons systems'; a political declaration outlining principles for the use of autonomous systems and promoting transparency; as well as various proposals to promote compliance with international law through practical measures, best practice guides and information-sharing arrangements, including the promotion and harmonization of legal weapons reviews.[110]
- There is also growing interest in the elaboration of multilateral standards on armed UAVs, which could have a bearing on swarms. The UN Institute for Disarmament Research has recommended the initiation of a transparent and inclusive multilateral process on this issue,[111] and the EU has urged the promotion of 'a UN-based legal framework which strictly stipulates that the use of armed drones has to respect international humanitarian and human rights law'.[112] The US is reportedly leading a process to further develop a political declaration from 2016 for the export and subsequent use of 'armed or strike-enabled UAVs',[113] and efforts are underway to ensure export control regimes and the Arms Trade Treaty adequately capture existing and future armed drones, including drone swarms.[114]

More generally, swarms bring to the fore urgent questions about appropriate spatial and temporal constraints on the use of force (and surveillance), expectations in terms of human control and responsibility in the use of (armed) force and our evolving understanding of what is justifiable by military necessity and what constitutes unnecessary suffering or an affront to human dignity. Whereas a dedicated political process specifically to control swarms may not be expedient at this time, the many issues raised by swarms underscore the need to collectively address these underlying concerns in weapons control debates, and to do so in a manner that takes account of ongoing efforts aimed at developing swarms.

The scenarios presented by both proponents and opponents of swarms underscore the risk that long-standing normative constraints on the use of force could be eroded. Only if states reaffirm, in deliberations and practice, the values enshrined in existing laws and actively seek to clarify the legal ramifications of new weapons technologies, can procedures aimed at ensuring compliance with the law, such as legal reviews of weapons, effectively contribute to the control of weapons and to disarmament. Without this, existing legal criteria will continue to 'shift or soften'[115] as new practices and technologies of violence take hold. Clear, shared standards can help counter norm erosion. Adopting regulations on autonomous weapons, defining limits on the use of armed drones and agreeing on standards to respond to the harms they cause would go a long way in addressing concerns raised by swarms.

Finally, from the perspective of disarmament, the debate about swarms highlights the need for a wider conversation on military applications of developments in science and technology. The portrayal of swarms parallels the promissory discourse dominating discussions on other emerging weapons technologies. A more critical, reflexive engagement with developments in science and technology of relevance to disarmament could help address patterns of harm from armed violence, rather than perpetuating them with novel technologies.[116] Proposed changes to military paradigms 'necessitated' by visions of swarm warfare raise wider societal questions about how wars should be fought in the future and what role technologies should play in that regard. States should take the opportunity to share their views on these questions in their submissions to the UN Secretary-General's updated report on recent developments in science and technology and their potential impact on international security and disarmament efforts.[117]

NOTES

1 UK Ministry of Defence et al, '£2.5m Injection for Drone Swarms', press release, GOV.UK, https://www.gov.uk/government/news/25m-injection-for-drone-swarms.

2 S. Russell et al, 'Why You Should Fear "Slaughterbots" – A Response', *IEEE Spectrum: Technology, Engineering, and Science News*, 23 January 2018, https://spectrum.ieee.org/automaton/robotics/artificial-intelligence/why-you-should-fear-slaughterbots-a-response. Framing concern about autonomous weapons and swarms in terms of 'weapons of mass destruction' can be critiqued on various grounds. But even commentators rejecting the scenario of terrorists launching thousands of 'slaughterbots' consider it 'a reasonable possibility' that they could release '[s]omething like a truck full of 50 drones' (P. Scharre, 'Why You Shouldn't Fear "Slaughterbots"', *IEEE Spectrum*, 22 December 2017, https://spectrum.ieee.org/automaton/robotics/military-robots/why-you-shouldnt-fear-slaughterbots).

3 D. Gayle, 'UK, US and Russia Among Those Opposing Killer Robot Ban', *The Guardian*, 29 March 2019, https://www.theguardian.com/science/2019/mar/29/uk-us-russia-opposing-killer-robot-ban-un-ai. Similarly, regarding Australia, see K. Finnane, 'Killerbots, Guided by Pine Gap, Same as Any Other Weapon?', *Alice Springs News Online*, 2 April 2019, http://www.alicespringsnews.com.au/2019/04/02/killerbots-same-as-any-other-weapon-argues-australia-at-un/.

4 S. J. A. Edwards, 'Swarming and the Future of Warfare', Dissertation in Partial Fulfilment of the Requirements of the Doctoral Degree in Public Policy Analysis, Pardee Rand Graduate School, 2005, pp. 179–286.

5 'On the homeland security front, security swarms equipped with chemical, biological, radiological, and nuclear (CBRN) detectors, facial recognition, anti-drone weapons, and other capabilities offer defenses against a range of threats' (Z. Kallenborn, 'The Era of the Drone Swarm Is Coming, and We Need to Be Ready for It', Modern War Institute, 25 October 2018, https://mwi.usma.edu/era-drone-swarm-coming-need-ready/.)

6 This bulletin does not address issues raised by satellite swarms. See, e.g., 'Satellite Swarms Dynamics and Control', European Space Agency, https://www.esa.int/gsp/ACT/projects/swarmcontrol.html; M. Bartels, 'Tiny Satellites Pose a Swarm of Opportunities — And Threats', Space.com, 5 December 2018, https://www.space.com/42621-tiny-satellites-offer-opportunities-and-threats.html.

7 P. Scharre, *Robotics on the Battlefield Part II: The Coming Swarm*, Center for a New American Security, October 2014, p. 5, https://s3.amazonaws.com/files.cnas.org/documents/CNAS_TheComingSwarm_Scharre.pdf?mtime=20160906082059. 'Swarming, coordinated action can enable synchronized attack or defense, more efficient allocation of assets over an area, self-healing networks that respond to enemy actions or widely distributed assets that cooperate for sensing, deception and attack' (ibid, p. 6).

8 The Preamble to the Convention on Certain Conventional Weapons (CCW), equally concerned with the prevention of unnecessary suffering, the protection of civilians, the ending of the arms race and disarmament attests to this. See, e.g., O. Bring, 'Regulating Conventional Weapons in the Future – Humanitarian Law or Arms Control?', 24(3) *Journal of Peace Research* (1987); K. Carter, 'New Crimes Against Peace: The Application of International Humanitarian Law Compliance and Enforcement Mechanisms to Arms Control and Disarmament Treaties', The Markland Group and Canadian Council on International Relations (eds), *Treaty Compliance: Some Concerns and Remedies*, 1998.

9 J. Arquilla and D. Ronfeldt, *Swarming and the Future of Conflict*, RAND Corporation, 2000, p 50, https://www.rand.org/pubs/documented_briefings/DB311.html. See also Edwards, 'Swarming and the Future of Warfare', p. 66 and Appendix A. 'Swarming involves the convergent action of several units that continue to attack by dispersing, maneuvering, and reinitiating combat (pulsing)' (ibid, p. 66).

10 Arquilla and Ronfeldt, Swarming and the Future of Conflict, pp. vii, 6, 43. Arquilla and Ronfeldt cite the tactics of 'generations of terrorists and criminals', the Zapatista movement and the International Campaign to Ban Landmines in support of their thesis (ibid, p. 2).

11 Edwards, 'Swarming and the Future of Warfare', p. 68.

12 See, e.g., R. Gorrell et al, 'Countering A2/AD with Swarming', Research Report Submitted to the Faculty in Partial Fulfilment of the Graduation Requirements for the Degree of Master of Operational Arts and Sciences, AIR Command and Staff College, Air University, 2016.

13 I. Lachow, 'The Upside and Downside of Swarming Drones', 73(2) *Bulletin of the Atomic Scientists* (4 March 2017) 96, https://doi.org/10.1080/00963402.2017.1290879.

14 On swarm robotics, see, e.g., H. Hamann, *Swarm Robotics: A Formal Approach*, 2018; G. Valentini, *Achieving Consensus in Robot Swarms*, 2017.

15 See, e.g., A. L. Alfeo et al, 'Swarm Coordination of Mini-UAVs for Target Search Using Imperfect Sensors', 12(2) *Intelligent Decision Technologies* (7 March 2018) 149–62, https://doi.org/10.3233/IDT-170317.

16 Lachow, 'The Upside and Downside of Swarming Drones', 97.

17 D. Hambling, *Change in the Air: Disruptive Developments in Armed UAV Technology*, UN Institute for Disarmament Research (UNIDIR), 2018, p. 5, http://www.unidir.org/files/publications/pdfs/-en-726.pdf.

18 Scharre, *The Coming Swarm*, pp. 35, 38. Scharre envisages that 'a human might task a swarm of missiles with a set of targets, but let the missiles coordinate among themselves to determine which missile will hit which target', or 'a human might task a group of vehicles to maintain coverage over an area ... and the vehicles might coordinate to determine how best to cover the area' (ibid, p. 36).

19 Ibid, p. 38.

20 Z. Kallenborn and P. C. Bleek, 'Swarming Destruction: Drone Swarms and Chemical, Biological, Radiological, and Nuclear Weapons', *The Nonproliferation Review* (2 January 2019) 4.

21 V. Boulanin and M. Verbruggen, *Mapping the Development of Autonomy in Weapon Systems*, SIPRI, November 2017, p. 63, https://www.sipri.org/sites/default/files/2017-11/siprireport_mapping_the_development_of_autonomy_in_weapon_systems_1117_1.pdf.

22 M. N. Schmitt and J. S. Thurnher, '"Out of the Loop": Autonomous Weapon Systems and the Law of Armed Conflict', 4 *Harvard Law School National Security Journal* (2013) 271, http://harvardnsj.org/wp-content/uploads/2013/01/Vol-4-Schmitt-Thurnher.pdf.

23 Kallenborn, 'The Era of the Drone Swarm Is Coming'.

24 E. Kania, 'Swarms at War: Chinese Advances in Swarm Intelligence', 17(9) *China Brief* (6 July 2017), https://jamestown.org/program/swarms-war-chinese-advances-swarm-intelligence/.

25 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems*, p. 63.

26 K. Osborn, 'Air Force Developing Swarms of Mini-Drones', Military.com, 27 May 2015, https://www.military.com/defensetech/2015/05/27/air-force-developing-swarms-of-mini-drones.

27 Scharre, *The Coming Swarm*, p. 31.

28 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems*, p. 63.

29 'Modern air-launched decoys like the Miniature Air-Launched Decoy, or MALD, are smaller and more capable than their predecessors. Able to fly complex routes and to carry out evasive manoeuvres, these systems are effectively single-use UAVs. These systems can carry a range of payloads. Some decoys like the MALD-J carry electronic warfare radar-jamming technology, and Raytheon has tested a version with a warhead to destroy defensive systems' (Hambling, *Change in the Air*, p. 3.)

30 UK Ministry of Defence et al, '£2.5m Injection for Drone Swarms'.

31 NATO, *Technology Trends Survey: Future Emerging Technology Trends*, NATO HQ Supreme Allied Commander Transformation, Defence Planning Policy and Analysis Branch, February 2015, p. 32, https://www.act.nato.int/images/stories/events/2012/fc_ipr/technology_trend_survey_v3.pdf.

32 Hambling, *Change in the Air*, p. 12.

33 Scharre, *The Coming Swarm*, p. 30.

34 T. Nurking, 'Wonders at the Threshold: Operational Priorities, Tensions and the Future of Military Platforms and Systems', Q. Ladetto (ed.), *Defence Future Technologies: What We See on the Horizon*, November 2017, 55.

35 Whereas it is often argued that swarms would be 'dramatically cheaper than standalone weapons systems' in service (e.g. Lachow, 'The Upside and Downside of Swarming Drones', 98. For a more nuanced argument about cost, see Scharre, *The Coming Swarm*, pp. 13–16. Shmuel has cautioned that '[n]othing can simultaneously be cheap, fast, maneuvrable, and have long range' (S. Shmuel, 'The Coming Swarm Might Be Dead on Arrival', War on the Rocks, 10 September 2018, https://warontherocks.com/2018/09/the-coming-swarm-might-be-dead-on-arrival/)

36 Scharre, *The Coming Swarm*, p. 30.

37 NATO, *Technology Trends Survey*, p. 32.

38 Kallenborn, 'The Era of the Drone Swarm Is Coming'.

39 G. Vásárhelyi et al, 'Optimized Flocking of Autonomous Drones in Confined Environments', 3(20) *Science Robotics* (18 July 2018) 2.

40 Shmuel argues that '[t]ruly large swarms will have to be made of simple machines, with either limited speed, limited range, limited protection (both physical and electronic), limited or cheap payload – and probably all of the above. If either the platform or its payload is not cheap and simple to mass produce, the very idea of the swarm – the multitude – will be undermined' (Shmuel, 'The Coming Swarm Might Be Dead on Arrival'). See also A. McCullough, 'The Looming Swarm', *Air Force Magazine*, http://www.airforcemag.com/MagazineArchive/Pages/2019/April%202019/The-Looming-Swarm.aspx, quoting the US Air Force acquisition chief: '[B]efore swarming can move "beyond the world of science and technology," … questions do need to be answered: "How do you certify it? How do you test it and evaluate it? Who owns it? Is it a weapons system? Does the platform using it own the autonomy – and swarming and collaboration – or is there a program for swarming and collaboration that plugs that autonomy into all sorts of platforms?"'.

41 Hambling, *Change in the Air*, p. 2; Scharre, *The Coming Swarm*, p. 37.

42 UN General Assembly, Ways and means for making the evidence of customary international law more readily available, Memorandum of the Secretariat, UN doc A/77/172, 14 February 2019, §77. See also McCullough, 'The Looming Swarm', citing a DARPA programme manager: '"This is something that can be implemented within the next year or two years and actually be used with our current weapons system, or derivatives of our current weapons system."'

43 In 2017, the US military completed its MAST (Micro Autonomous Systems and Technology) research programme, launched in 2008 with the goal of understanding technologies that enable autonomous micro-robots to work together (D. McNally, 'Army Completes Autonomous Micro-Robotics Research Program', US Army Research Laboratory, 25 August 2017, https://www.arl.army.mil/www/default.cfm?article=3065).

44 'Raytheon Gets $29m for Work on US Navy LOCUST UAV Prototype', *Naval Today*, 28 June 2018, https://navaltoday.com/2018/06/28/raytheon-wins-contract-for-locus-inp/. See also D. Smalley, 'News: Navy's Autonomous Swarmboats Can Overwhelm Adversaries', Office of Naval Research, 14 April 2015, https://www.onr.navy.mil/en/Media-Center/Press-Releases/2015/LOCUST-low-cost-UAV-swarm-ONR.

45 Perdix drones are 3D-printed and weigh 290 grams, with a wingspan of around 30 cm ('Perdix Fact Sheet', Office of the [US] Secretary of Defense, n.d., https://dod.defense.gov/Portals/1/Documents/pubs/Perdix%20Fact%20Sheet.pdf?ver=2017-01-09-101520-643).

46 J. Gimber, 'The Rise of the Drone Swarm', *UK Defence Journal*, 15 February 2019, https://ukdefencejournal.org.uk/the-rise-of-the-drone-swarm/.

47 DARPA, 'Friendly 'Gremlins' Could Enable Cheaper, More Effective, Distributed Air Operations', 28 August 2015, https://www.darpa.mil/news-events/2015-08-28.

48 'CODE Demonstrates Autonomy and Collaboration with Minimal Human Commands', DARPA, 19 November 2018, https://www.darpa.mil/news-events/2018-11-19.

49 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems,* p. 31; D. Smalley, 'News – Autonomous Swarmboats: New Missions, Safe Harbors', Office of Naval Research, 14 December 2016, https://www.onr.navy.mil/en/Media-Center/Press-Releases/2016/Autonomous-Swarmboats.

50 S. N. Romaniuk and T. Burgers, 'China's Swarms of Smart Drones Have Enormous Military Potential', *The Diplomat,* 3 February 2018, https://thediplomat.com/2018/02/chinas-swarms-of-smart-drones-have-enormous-military-potential/; D. Hambling, 'If Drone Swarms Are the Future, China May Be Winning', *Popular Mechanics,* 23 December 2016, https://www.popularmechanics.com/military/research/a24494/chinese-drones-swarms/.

51 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems,* p. 102. See also Kania, 'Swarms at War'.

52 European Defence Agency, 'Pilot Project EuroSWARM and SPIDER activities completed', 23 February 2018, https://www.eda.europa.eu/info-hub/press-centre/latest-news/2018/02/23/pilot-project-euroswarm-and-spider-activities-completed.

53 Boulanin and Verbruggen, *Mapping the Development of Autonomy in Weapon Systems*, p. 197.

54 UK Ministry of Defence and The Rt Hon Gavin Williamson CBE MP, 'Defence in Global Britain', speech by Defence Secretary Gavin Williamson, GOV.UK, 11 February 2019, https://www.gov.uk/government/speeches/defence-in-global-britain.

55 V. Insinna, 'French Air Force Chief: France and Germany Working on Export Controls for Future Fighter', *Defense News*, 8 February 2019, https://www.defensenews.com/global/europe/2019/02/08/french-air-force-chief-france-and-germany-working-on-export-controls-for-future-fighter/.

56 Hambling, *Change in the Air*, pp. 5–6.

57 'To … increase the effectiveness of small-unit combat forces operating in urban environments, DARPA has launched its new OFFensive Swarm-Enabled Tactics (OFFSET) program. OFFSET seeks to develop and demonstrate 100+ operationally relevant swarm tactics that could be used by groups of unmanned air and/or ground systems numbering more than 100 robots' (DARPA, 'OFFSET Envisions Swarm Capabilities for Small Urban Ground Units', 7 December 2016, https://www.darpa.mil/news-events/2016-12-07).

58 '[I]n the far-term, humans will form integrated teams with nearly fully autonomous unmanned systems, capable of carrying out operations in contested environments. This could include heterogeneous swarms of UAS directly supporting soldiers on the ground through ISR or aerial strikes' (US Department of Defense, Unmanned Systems Integrated Roadmap 2017–2042, 28 August 2018, p. 21, https://www.documentcloud.org/documents/4801652-UAS-2018-Roadmap-1.html#document).

59 T. Eshel, 'Russian Forces in Syria Repelled Massive Drone Attack on Hmeimim and Tartus', *Defense Update*, 8 January 2018, https://defense-update.com/20180108_uav_attack.html; 'Houthis Destroyed UAE Patriot System in Central Yemen With Swarm of Drones – Reports', *South Front*, 24 February 2018, https://southfront.org/houthis-destroyed-uae-patriot-system-in-central-yemen-with-swarm-of-drones-reports.

60 Scharre, *The Coming Swarm*, p. 26. See, e.g., Hamann, *Swarm Robotics*, pp. 96 et seq.

61 Lachow warns that '[w]hen a system is reacting in real time to a dynamically changing environment, and basing its decisions on a simple set of rules, it is possible that unanticipated behaviours will naturally arise' (Lachow, 'The Upside and Downside of Swarming Drones', 98). In 2018, the UN Secretary-General noted that due to the complexity of an artificial intelligence system, 'the outputs of such a system may never be entirely predictable or explainable. Moreover, this unpredictability means that when algorithms fail, they do so in ways an operator never would' (Report of the Secretary-General on current developments in science and technology and their potential impact on international security and disarmament efforts, UN doc A/73/177, 17 July 2018, §15).

62 Importantly, these challenges go beyond protection from attacks. See, in particular, C. Jenks and R. Liivoja, 'Machine Autonomy and the Constant Care Obligation', *Humanitarian Law & Policy*, 11 December 2018, https://blogs.icrc.org/law-and-policy/2018/12/11/machine-autonomy-constant-care-obligation/.

63 See, e.g., A*utonomous Weapons Systems: Technical, Military, Legal and Humanitarian Aspects*, expert meeting report, Geneva, Switzerland, 26 to 28 March 2014, ICRC, November 2014, https://www.icrc.org/en/document/report-icrc-meeting-autonomous-weapon-systems-26-28-march-2014; M. Brehm, *Defending the Boundary: Constraints and Requirements on the use of Autonomous Weapon Systems under International Humanitarian and Human Rights Law*, Academy Briefing no 9, Geneva Academy of International Humanitarian Law and Human Rights, May 2017, https://www.geneva-academy.ch/joomlatools-files/docman-files/Briefing9_interactif.pdf.

64 Report of the 2016 Informal Meeting of Experts on Lethal Autonomous Weapons Systems (LAWS), UN doc CCW/CONF.V/2, 10 June 2016, §40.

65 Ibid, §67.

66 Ibid, §68.

67 '[L]arge numbers of low-cost attritable robotics can be controlled en masse by a relatively small number of human controllers' (Scharre, *The Coming Swarm*, p. 14).

68 Ibid, p. 40.

69 The reconfiguration of human-machine relations could place unacceptable demands on operators. Scharre notes that '[h]uman performance modification technologies, including pharmaceuticals … or other modification techniques, such as transcranial direct current stimulation (tDCS), could allow humans to pay attention, process information and react faster' but cautions that ethical and social issues need to be addressed (ibid, p. 34). A former UN Special Rapporteur on extrajudicial, summary or arbitrary executions warned in respect of swarms 'that technology is being developed that is beyond humans' capacity to supervise effectively and in accordance with applicable law [and that u]nless adequate precautions are taken and built into systems, the likelihood increases that mistakes will be made which will amount to clear violations of the applicable laws' (Interim report by the Special Rapporteur on extrajudicial, summary or arbitrary executions, UN doc A/65/321, 23 August 2010, §41).

70 Z. Kallenborn and P. C. Bleek, 'Drones of Mass Destruction: Drone Swarms and the Future of Nuclear, Chemical, and Biological Weapons', *War on the Rocks*, 14 February 2019, https://warontherocks.com/2019/02/drones-of-mass-destruction-drone-swarms-and-the-future-of-nuclear-chemical-and-biological-weapons/. Scharre argues that '[w]hile autonomous systems may not be more susceptible to spoofing or cyber attacks, the consequences if an enemy were to gain control of a highly autonomous system – or an entire swarm – could be much greater' (P. Scharre, 'Counter-Swarm: A Guide to Defeating Robotic Swarms', War on the Rocks, 31 March 2015, https://warontherocks.com/2015/03/counter-swarm-a-guide-to-defeating-robotic-swarms/).

71 See, e.g., *Article 36, Drones in the Use of Force: A Way Forward*, Briefing Paper, October 2018, https://www.efadrones.org/wp-content/uploads/2018/10/A36-drones-use-of-force-way-forward.pdf.

72 'The Air Force has long discussed using swarms of miniaturized drones for attack and surveillance missions … commanders can use the swarm for a single objective, like a major attack, or disperse the bots across a region for 24/7 surveillance' (L. Seligman, 'How Swarming Drones Could Change the Face of Air Warfare', *Defense News,* 17 May 2016, https://www.defensenews.com/2016/05/17/how-swarming-drones-could-change-the-face-of-air-warfare/).

73 'Attritable UAVs can be used with even less political consequence than existing armed UAVs as they are so easily replaced. Another aspect of UAVs is that they are increasingly difficult to attribute' (Hambling, *Change in the Air*, p. 14.)

74 Scharre, *The Coming Swarm*, p. 33.

75 Lachow, 'The Upside and Downside of Swarming Drones', 100.

76 J.-M. Rickli, 'The Impact of Autonomous Weapons System on International Security and Strategic Stability', in Q. Ladetto (ed.), *Defence Future Technologies*, p. 63.

77 '[S]mall UAVs are not regulated and would not require an extensive scientific research or industrial base to produce. Manufacture would be relatively hard to spot – compared to the production of traditional military hardware such as manned aircraft, ships or ballistic missiles – as it would resemble any other consumer electronics assembly' (Hambling, *Change in the Air,* p. 12).

78 T. X. Hammes, *Technologies Converge and Power Diffuses: The Evolution of Small, Smart, and Cheap Weapons*, Policy Analysis, Cato Institute, 27 January 2016, p. 5, https://www.cato.org/publications/policy-analysis/technologies-converge-power-diffuses-evolution-small-smart-cheap#full.

79 E.g. J. Kraska and R. Pedrozo, 'China's Capture of U.S. Underwater Drone Violates Law of the Sea', Lawfare, 16 December 2016, https://www.lawfareblog.com/chinas-capture-us-underwater-drone-violates-law-sea.

80 Hambling, *Change in the Air*, p. 1.

81 AeroVironment, 'Switchblade', Datasheet, 2017, https://www.avinc.com/images/uploads/product_docs/SB_Datasheet_2017_Web_rv1.1.pdf.

82 M. Bolton and W. Zwijnenburg, 'Futureproofing the Draft Arms Trade Treaty: A Policy Brief', 21 March 2013, https://politicalminefields.files.wordpress.com/2013/03/futureproofing-the-draft-arms-trade-treaty-42.pdf.

83 Under what conditions is a swarm, respectively its components, a 'weapon', 'weapon system', 'unmanned aerial vehicle', 'unmanned combat aircraft', or a mixture thereof? See Program on Humanitarian Policy and Conflict Research, Commentary on the Manual on International Law Applicable to Air and Missile Warfare, Harvard University, 2010, pp. 54–56.

84 See, in particular, A. Norris, *Legal Issues Relating to Unmanned Maritime Systems*, US Naval War College, 2013, pp. 21–64, https://www.hsdl.org/?view&did=731705; M. N. Schmitt and D. S. Goddard, 'International Law and the Military Use of Unmanned Maritime Systems', 98(902) *International Review of the Red Cross* (August 2016) 567–92, Kraska and Pedrozo, 'China's Capture of U.S. Underwater Drone Violates Law of the Sea'.

85 Hammes, *Technologies Converge and Power Diffuses*, p. 9.

86 Scharre, *The Coming Swarm*, p. 20.

87 Ibid, pp. 10, 15, 20, 29.

88 In addition, saturation with explosive force is one of the counter-measures to swarms under discussion. Shmuel envisages engaging swarms 'with large volumes of dumb and cheap munitions' (Shmuel, 'The Coming Swarm Might Be Dead on Arrival'). Directed energy weapons are also explored as countermeasures, raising a host of concerns, including for the protection of infrastructure critical to civilian wellbeing. See, e.g., K. Mizokami, 'The Army's Real-Life "Phaser" Would Knock Out an Entire Drone Swarm with One Shot', *Popular Mechanics*, 14 November 2016, https://www.popularmechanics.com/military/weapons/a23881/the-army-is-testing-a-real-life-phaser-weapon/; Article 36, *Directed Energy Weapons*, Discussion Paper, November 2017, http://www.article36.org/wp-content/uploads/2019/06/directed-energy-weapons.pdf

89 K. Mizokami, 'The Army Wants Artillery Rockets That Blast Swarms of Tank-Killing Drones Into the Sky', *Popular Mechanics*, 7 February 2017, https://www.popularmechanics.com/military/weapons/a25090/army-rocket-launched-tank-killing-quadcopters/.

90 For a discussion, see M. Homayounnejad, *Autonomous Weapon Systems, Drone Swarming and the Explosive Remnants of War,* TLI Think! Paper 1/2018, Kings College London, 2018, pp. 47–61.

91 Ibid, p. 12.

92 Homayounnejad notes that although research into using drones in such environments has thus far focused on unarmed drones, 'the research potentially has applications for swarms of explosive munitions' (ibid, p. 10).

93 Ibid, p. 12.

94 Ibid, p. 33.

95 Hambling, *Change in the Air*, p. 14 (emphasis added).

96 See, e.g., N. Melzer, T*argeted Killing in International Law*, 2008; Study on Targeted Killings, Report of the Special Rapporteur on extrajudicial, summary or arbitrary executions, Philip Alston, Addendum, UN doc A/HRC/14/24/Add.6, 28 May 2010.

97 Russell et al, 'Why You Should Fear "Slaughterbots"'.

98 These norms are enshrined in the 1868 Declaration Renouncing the Use, in Time of War, of Explosive Projectiles Under 400 Grammes Weight (St. Petersburg Declaration).

99 See, e.g., Scharre, 'Why You Shouldn't Fear "Slaughterbots"' and Homayounnejad, who considers that deploying a 'one-gram shaped charge to puncture the human cranium … clearly offers law-abiding militaries a great deal of utility' (Homayounnejad, *Autonomous Weapon Systems, Drone Swarming and the Explosive Remnants of War,* pp. 10–11). Similarly, Kallenborn and Bleek put forth the view that 'the ability of drone swarms to serve as sophisticated chemical- and biological-weapon (CB) delivery systems could significantly increase the utility of these weapons' without any reference to the unequivocal, comprehensive bans under treaty and customary international law of chemical and biological weapons (Z. Kallenborn and P. C. Bleek, 'Swarming Destruction', 3).

100 Nurkin, 'Wonders at the Threshold', p. 55; *NATO, Technology Trend Survey: Future Emerging Technology Trends*, NATO HQ Supreme Allied Commander Transformation, Long Term Requirements Branch, September 2011, p. 52, http://indianstrategicknowledgeonline.com/web/Technology_Trend_Survey_Final%20Version_Publish.pdf.

101 In a report published in July 2018, the UN Secretary-General remarks in relation to the research agenda of UNIDIR that '[p]otentially important areas of inquiry do not always generate support from donors … because cutting-edge issues may not yet be on the multilateral disarmament agenda, for example, developments in drone swarming technology' (Thirty-Fifth Anniversary of the United Nations Institute for Disarmament Research: Report of the Secretary-General, 31 July 2018, UN doc A/73/284, § 29).

102 Report of the Secretary-General on current developments in science and technology and their potential impact on international security and disarmament efforts, §10.

103 Scharre, *The Coming Swarm*, p. 35.

104 Ibid, pp. 36, 41.

105 Homayounnejad, *Autonomous Weapon Systems*, pp. 61, 63.

106 Ibid, pp. 15, 18.

107 For example, there was a discussion of 'how meaningful human control could be applied over autonomous swarms' during the 2018 session of the CCW Group of Governmental Experts (GGE) (Report of the 2018 session of the Group of Governmental Experts on Emerging Technologies in the Area of Lethal Autonomous Weapons Systems, UN doc CCW/GGE.1/2018/3, 23 October 2018, §32).

108 For more information, see The United Nations Office at Geneva, '2019 Group of Governmental Experts on Lethal Autonomous Weapons Systems (LAWS)', https://www.unog.ch/80256EE600585943/(httpPages)/5C00FF8E35B6466DC125839B003B62A1?OpenDocument.

109 Scharre considers that '[w]hile militaries will need to embrace automation for some purposes, humans must also be kept in the loop on the most critical decisions, particularly those that involve the use of force or movements and actions that could potentially be escalatory in a crisis' (Scharre, *The Coming Swarm*, pp. 33 and 34). See also the website of the Campaign to Stop Killer Robots, https://www.stopkillerrobots.org.

110 Report of the 2018 session of the GGE on Emerging Technologies, §§28, 40–54.

111 UNIDIR, *Increasing Transparency, Oversight and Accountability of Armed Unmanned Aerial Vehicles*, 2017, p. 1, http://www.unidir.org/files/publications/pdfs/increasing-transparency-oversight-and-accountability-of-armed-unmanned-aerial-vehicles-en-692.pdf.

112 European Parliament recommendation to the Council on the 73rd session of the United Nations General Assembly, EU doc 2018/2040(INI), 5 July 2018, http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P8-TA-2018-0312&language=EN&ring=A8-2018-0230. See also The European Forum on Armed Drones, Call to Action, https://www.efadrones.org/call-to-action/.

113 U.S. Department of State, Joint Declaration for the Export and Subsequent Use of Armed or Strike-Enabled Unmanned Aerial Vehicles (UAVs), Media Note, 28 October 2016, https://2009-2017.state.gov/r/pa/prs/ps/2016/10/262811.htm.

114 '[A]rmed unmanned aerial vehicles are covered by categories IV and V of the [UN] Register [of Conventional Arms]' (Continuing operation of the United Nations Register of Conventional Arms and its further development: Note by the Secretary-General, UN doc A/68/140, 15 July 2013, p. 2). See also R. Stohl and S. Dick, *The Arms Trade Treaty and Drones*, Stimson Center, August 2018, p. 12: 'it is important for stakeholders to ask how to make controls over drone technologies sustainable. When thinking about technological innovations for UAVs – particularly outside military categories – it is helpful to identify characteristics of drones that pose particular security concerns that require greater oversight and control. These may include characteristics ... such as ... swarming capability', https://www.stimson.org/sites/default/files/file-attachments/Stimson_The%20Arms%20Trade%20Treaty%20and%20Drones_August%202018.pdf.

115 Schmitt and Goddard, 'International Law and the Military Use of Unmanned Maritime Systems', 579.

116 E.g., Homayounejad trusts that 'the technical features of LAWS munitions will raise the bar of what is "possible" and "practical"' in relation to recording and clearance requirements given the advanced data collection and storage capacities of such devices (Homayounnejad, *Autonomous Weapon Systems*, p. 34). Similar arguments were made about armed drones in respect of casualty recording. Yet, unprecedented technical capabilities for observing and documenting drone strikes have not thus far translated into greater transparency and accountability.

117 UNGA Res 73/32, 11 December 2018, operative §4.

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