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Article36

Science, technology and weaponization: preliminary observations

Discussion paper for the Convention on Certain Conventional Weapons (CCW)

Geneva, November 2017

Article 36 is a UK-based not-for-profit organisation working to promote public scrutiny over the development and use of weapons.*

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'Clearly, we are capable of creating an ungovernable world.'[1]

'[T]he future confronts us with the paradox that we need to make decisions although we know that no informed decisions are possible.'[2]

Summary and initial recommendations

The continuous process of development in science and technology (S&T) has ongoing implications for the emergence of new weapons, means and methods of warfare and other security applications. Such developments, in turn, may raise concerns regarding human wellbeing, environmental protection and international peace and security, which may provoke new questions regarding the application and sufficiency of existing legal frameworks. New and changing military technologies can present significant risks to life and precipitate dramatic changes in the balance of international relations. This should, therefore, be an issue of considerable significance to the international community.

Early consideration of developments in S&T, at the multilateral level, can provide a framework for the identification of risks, serving in turn to shape expectations and develop necessary responses. Yet there is no multilateral body that reviews developments in S&T in relation to conventional weapons, means and methods of warfare. With its open architecture and flexible agenda, the UN Convention on Certain Conventional Weapons (CCW) can provide an appropriate framework to give consideration to such developments.

Working in cooperation or informal coordination with other relevant bodies, such as the Biological Weapons Convention (BWC), the Chemical Weapons Convention (CWC) and the First Committee of the UN General Assembly, the CCW could ensure that the current multilateral framework maintains a comprehensive oversight of how developments in S&T may create risks or legal uncertainties in the future.

Such an S&T review, in relation to conventional weapons, can:

- serve to build mutual confidence and understanding, by increasing transparency and reducing uncertainty regarding S&T developments with potential security implications;
- facilitate assessment and understanding of how fundamental principles of existing law, as well as specific legal rules, should be expected to be applied as developments in S&T are proposed for weaponization;
- serve a 'precautionary' function, supporting other measures aimed at preventing risk or illegality, including national legal reviews of new weapons, means and methods of warfare;
- foster dialogue, drawing on technical and political expertise, to help ensure that technologies brought into military operation accord with shared understandings of what is right or wrong and that technological development pursues desirable goals.

Movement towards fulfilling such functions would take time and would need to be responsive to the practical and political context of

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the CCW framework. In the current context, where consideration of S&T review is at a very early stage of discussion in the CCW, Article 36 suggests that High Contracting Parties to the CCW should:

- call for discussions on an effective international framework to ensure scrutiny of S&T developments with implications for conventional weapons, and that the international legal framework on weapons and security provides a comprehensive coverage of new developments;
- convene an informal meeting in 2018 to consider how relevant developments in S&T can be addressed within the framework of the Convention.

Introduction

Developments in science, technology and weapons

Developments in diverse areas of S&T have implications for the international policy and legal frameworks intended to govern weapons, means and methods of warfare. Innovations can both improve and undermine our ability to maintain effective arms control, disarmament and security regimes. For example, new technologies can help with the detoxification of chemical warfare agents,[3] whereas the fabrication of metal-free firearms might circumvent existing small arms control mechanisms.[4] Similarly, new technologies may allow greater control in the application of force, or may produce novel risks to human wellbeing.

Early consideration of possible military and security-sector applications of developments in S&T is important for building a shared understanding of potential risks and formulating adequate multilateral responses including, importantly, shaping the starting presumptions and orientations that inform such responses.

Reviewing science and technology in multilateral frameworks relevant to weapons and security

It is widely accepted that certain weapons technologies present particular legal and policy concerns, and that the 'right of the parties to an armed conflict to choose methods or means of warfare is not unlimited'.[5] Technologies are not static, and new developments can challenge the underlying principles and values enshrined in regulatory instruments. The drafters of the 1868 St Petersburg Declaration acknowledged this when they 'reserve[d] to themselves to come hereafter to an understanding whenever a precise proposition shall be drawn up in view of future improvements which science may effect in the armament of troops, in order to maintain the principles which they have established, and to conciliate the necessities of war with the laws of humanity'.[6]

More recently, acting on a proposal by Switzerland,[7] the 2016 Review Conference of the CCW acknowledged the key role of this instrument in 'monitoring ongoing and new developments in new weapons, means and methods of war', and decided to consider how relevant S&T developments can be addressed within the framework of that Convention, so as to ensure its 'continued relevance, integrity and adequacy'.[8]

Taking a broader approach, the UN General Assembly's First Committee adopted a resolution introduced by India in October 2017 that tasks the UN Secretary-General to report to the General Assembly on current developments in S&T and their potential impact on international security and disarmament efforts.[9]

Taken together, these developments pave the way for UN Member States to develop a holistic view of the implications of S&T in the context of international security and the legal framework governing weapons, means and methods of warfare. The reviewing of S&T in the context of specific legal instruments may help to inform the more general, cross-cutting considerations mandated by the First Committee. Those wider considerations may in turn help to identify issues that risk falling between the cracks of existing instruments.

About Article 36's science and technology project and this paper

Article 36's project on 'Science, Technology and Weaponization'[10] is designed to foster a better understanding of S&T developments relevant to the international control of conventional weapons, and to propose conceptual approaches that can aid discussion on an effective international framework to ensure scrutiny of such developments.

This initial summary report very briefly sets out some developments in fields of S&T that have potential implications for the multilateral control of conventional weapons. It then provides an overview of some general conceptual challenges and questions regarding the review of S&T developments. Finally, annexed to the report are papers considering specific questions and concerns that may be raised by the the military use of nanomaterials and by directed energy weapons as two, more detailed, examples. These annexes are also available as separate discussion papers.

Additional papers and a detailed report will be published in 2018.

Suggested areas of development in science and technology with implications for the multilateral control of weapons

Establishing processes to effectively review advances in S&T has been a key concern for multilateral weapons control for many years. Within the framework of the CWC, the Scientific Advisory Board of the Organisation for the Prohibition of Chemical Weapons assesses and reports on developments in S&T relevant to the Convention.[11] A review of developments in the field of S&T related to the BWC has been a standing agenda item at its meetings of experts and meetings of states parties since 2012.[12] There is reportedly significant support among states parties to strengthen the Convention's S&T review process,[13] though major challenges remain.[14] Such approaches illustrate a broad recognition that developments in S&T may present challenges to established legal instruments controlling categories of weapons.

No multilateral mechanism presently reviews developments in S&T with implications for the international control of conventional weapons. This section sets out some developments in fields of S&T that potentially have such implications. This is not intended to represent an exhaustive list, and does not prejudge whether a regulatory response of some kind is required.

Information and communication technologies represent an area of considerable global investment. Computing power continues to grow exponentially, with sensors, networking and other technologies advancing rapidly. Such developments have already had a significant impact on how militaries and security actors operate. Ever-increasing amounts of data are available, collected, analysed and communicated for military and security purposes with potential implications regarding privacy, surveillance and targeting.[15]

The continuing development within this field of **digital cognitive technologies** (those that emulate aspects of human cognition, such as computer vision, machine learning and natural language processing) offers various potential military applications. Some are already the subjects of research: imagery analysis using computer vision algorithms for target identification is one example.[16] The potential of 'human-machine teaming' to increase the speed of analysis, decision-making and action in military operations – using the relative strengths of human cognition and computer processing – has also been suggested.[17] Some of these developments are already the subject of deliberations by the CCW's Group of Governmental Experts on Lethal Autonomous Weapons Systems. Among other issues, concerns arise about the exercise of human control and judgement in decision-making on the use of force, as well as responsibility and accountability for the use of force.

Similar issues about control, compliance with legal standards and allocation of responsibility arise from military applications of advances in **cognitive neuroscience and related technologies**,[18] including brain-computer interface technologies[19] and other ways of closely integrating individuals with technologies. Potential applications include possibilities for enhanced learning and analysis capabilities for military personnel,[20] opportunities for automatic threat detection through measuring and using unconscious neural responses to visual information to feed into target selection,[21] and for the remote control of weaponry.[22] Neuro-enhancement technologies (which could include novel pharmaceuticals as well as devices) also raise ethical issues and risks of harm to military personnel that may require consideration, including from long-term invasive enhancement devices or the hacking of such technologies.[23]

Advances in the field of **materials science** will have military applications, with some being specifically researched for this purpose. The development of new energetic materials for weapons technology that is more lethal, smaller and safer for its operators to use, as well as the development of other materials that enable different constructions or advancements in weapons design, may be significant for conventional weapons control. Potential challenges posed by developments in this field also include effects on health and the environment, including novel injuries or diseases that may be produced by newly developed materials. The possibility of the development of weapons with greater destructive powers may also be a potential concern.

Advances in nanomaterials present a range of potential applications. These possibilities and issues they may raise are explored in more detail in the **Nanoweapons annex** to this report.

A further annex to this report considers Directed Energy Weapons, where research in the field of directed energy technologies is enabling greater movement towards weapons that use non-kinetic means to apply force to targets.

Reviewing science and technology: general conceptual considerations

Reviewing the implications of developments in S&T in relation to weapons entails confronting conceptual questions that are shared across efforts to manage wider issues of technology and society. In addition, the sphere of weapons and security presents specific challenges, particularly when approached at the multilateral level. This is due to weapons causing a certain degree of harm by design (which brings into play different policy and legal frameworks), their playing a central role in states' security policies and the secrecy that is often attendant upon this.

In this section, we provide an overview of some of the general conceptual issues regarding the review of S&T developments, and draw on examples of how weapon-related issues can highlight such challenges or raise additional ones.

What should be considered relevant?

An initial question facing a general S&T review relates to how it will recognize, classify and prioritize what should be considered relevant developments in the broad fields of S&T.

Whereas research into a new rocket launcher is readily identifiable as having military implications, many other technologies are said to be 'dual use' or to have 'multiple uses'. Looking further 'back' into areas of scientific innovation, any implications for future weapons may be even more difficult to assess. Thus, for example, underpinning scientific and technological developments have enabled the louder and more focused projection of sound, which may be brought into operational use as a tool for communication only for its capacity to cause pain or discomfort to reveal its potential as a weapon.

The notion of 'weaponization' implies that a technology is 'neutral' or 'civilian' by nature and is subsequently converted to military purposes. Yet, diverse research is funded or otherwise promoted by military agencies, sometimes explicitly with military applications, including weapons, in mind. Across this broad and sometimes opaque landscape, a general effort to review S&T developments will need to find a way to assess what is relevant.

What should be the focus of consideration?

Narrowing in from a question of what might be relevant, a review function will necessarily have to determine what should be the focus of further or deeper consideration. This in turn asks questions of the mandate of the body undertaking such a review in relation to those issues that are considered relevant.

Some S&T developments and attendant security practices can challenge the regulatory categories and boundaries around which existing control regimes are articulated. For example, the use of nanomaterials in the military context may blur the distinctions between chemical, biological or conventional weapons, or between small arms and heavy weapons. Developments in non-kinetic applications of force, including directed energy weapons, may blur the boundary between technologies traditionally reserved for military combat and instruments of force traditionally used in policing. This presents a risk of certain S&T developments falling 'between' existing mechanisms or institutions whose mandates orient themselves at these distinctions.

In a similar fashion, some S&T developments may risk undercutting long-standing opprobrium and normative protections against certain 'effects' of violence. Possible military applications of nanotechnology, for instance, may challenge legal norms against poisoning and blinding as methods of warfare if they create such effects without falling under the letter of existing instruments. If existing mechanisms are to effectively uphold the principles and values they are meant to give expression to, their scope must be interpreted flexibly enough to account for technologies that may function in novel ways but produce effects recognized as unacceptable.

Beyond such mandate questions, deciding that certain issues should be a focus of consideration may have political implications. Some might fear that simply focusing on a particular area of S&T development risks the possible imposition of some form of regulation. On the other hand, bringing an area of S&T within the realm of weapons-focused discussions may serve to 'securitize' it. This would actually further its 'weaponization' by normalizing the idea that it is the principles and concepts of security policy and weapons law, rather than other, potentially more demanding, policy and legal frameworks that are most relevant to its consideration.

How do we think about the future?

Utopian dreams and dystopian nightmares can dominate an S&T debate. The discourse is characterized by visionary scenarios and future-oriented rhetoric and imaginaries. Speculative, even fictional, technologies are granted the potential for revolutionary, transformative, transcendental or disruptive innovation.[24] At times, one future scenario is drawn on to promote another. For example, it is sometimes argued that it will be necessary to 'enhance' soldiers to keep pace with the ever-increasing speed of warfare brought about by increasing autonomy in weapon systems.

To 'bridge the gap between the present and the future', various conceptual tools have been developed, including prognostic tools of technology foresight and assessment.[25] Some conceive of technological development as a linear process from science fiction to science fact.[26] The concept of 'convergence' imagines different spheres of S&T coming together to create transformational changes. There is a danger that such accounts of technology developing along determined pathways disregard social dynamics in a way that is disempowering for bodies charged with governing science.[27] Among social scientists, it is widely accepted that the relationship between technology and innovation is not deterministic, but socially constructed, and that the adoption of certain classifications and presentation of future visions (whether positive or negative) may work politically towards certain ends.

A recognition of the social embeddedness of S&T should draw our attention to power relations. Rhetoric about convergence, for example, has attracted criticism for being used to shape the future it purportedly predicts, and to sidestep public debate about the goals of science policy and science policy makers.[28] The public and policy makers are invited to talk and think about emerging technologies on the premise that the nanoworld, AI world and enhanced-human world are upon us already.[29] This fosters a sense of 'inevitability' of technological and social change and works against the exercise of control and agency in shaping S&T developments.

Attention to power also invites questions about who is likely to benefit from certain advances in S&T. Whereas some S&T developments tend to be cast as the salvation or downfall of us all, others are portrayed as bringing an advantage to some states or people at the expense of others, or as strengthening national security to the detriment of international peace or human security.[30] There can be a tendency to prioritize short-term, narrow perceptions of utility (or potential utility) over longer-term wider goods. Similarly, national positions tend to give a strong voice to military concerns in order not to rule out pathways of technological development that may remain open to others (and, in so doing, accept a potential disadvantage). Conceptions of the national security interest, for many states, remain within a framing that is essentially competitive.

Although these dynamics create the potential for significant disagreement and discord in multilateral discussions on S&T of relevance to weapons control, recognition of potentially competing interests and disparate social and political implications is an argument for public scrutiny and multilateral review of S&T developments with a view to shaping their goals.

What is acceptable or desirable?

Whilst a general review mechanism may not be charged with making formal decisions regarding the status of different issues, it is likely to raise questions about what should be considered acceptable or desirable in the future. Such questions may revolve around whether the ethical concerns involved in continued development are surmountable and tolerable, and what information or evidence might be considered necessary in order to inform such opinions. Where technological changes occur incrementally, it can be difficult to identify or construct categorical ‘boundaries’ to ensure the technologies adopted accord with widespread conceptions of what is right or wrong.[31]

Although it may not seem possible to distinguish reliably between the desirable and the undesirable before the level of concrete applications has been reached,[32] it is also not sufficient only to assess a technology’s consequences; there should be some evaluation of the aims that are being sought during its development.[33] Questions about acceptability tend to concentrate on the moral (and legal) limits that have to be respected. They do not address whether something is good for the human situation in broad terms or whether it is really worth striving for.

These considerations raise questions about what information is needed in any general process of review, and what orientation should be taken towards issues of uncertainty, ambiguity or shortcomings of transparency.

What do we need to know?

Within multilateral considerations of weapons, the acceptability or desirability of a particular technology is a matter of framing, that is, of the central ideas that structure our understanding of the issues at stake, what is going on, why, what (if anything) needs to be done and who needs to do it.[34] Frames set up questions about what are conceptualized as harms, risks or benefits, and what evidence is needed to assess these. Assessments of acceptability and desirability in multilateral considerations of weapons technologies tend to be presented within the three basic frames sketched out below.

This is not to suggest, however, that these are the only possible frames. New technologies may well demand that we conceptualize harms, risks and benefits in novel ways if they are to be considered in the most appropriate manner.

How much harm vs. how much military benefit?

The dominant framing tends to be a form of cost-benefit analysis. Considering these questions with respect to prospective technologies is necessarily a difficult matter. Past consideration of existing weapons in multilateral fora has suggested some preference for considering harms primarily in terms of direct deaths and injuries, with less consideration of longer-term, indirect or less tangible harms that may be caused (e.g. from the incidental destruction of infrastructure vital to the civilian population). Military benefit, on the other hand, is argued by some in broad terms (e.g. ranging from more powerful explosive munitions to better protection of own forces). With respect to existing weapons, there is no agreement on how the scale of these different factors is to be understood, what timeframe such factors should be considered over or what counts as concrete evidence regarding the effects in question. Seeking to balance estimations of such effects with respect to future technological developments is thus more likely to fall back on prior presumptions regarding their acceptability or unacceptability.

Evidence that may be relevant to this framing could include the ‘scale’ of effects of a weapon system (i.e. over what area or time might people or objects be affected by its use?), how powerful these effects are (i.e. how much damage may be done to certain objects?) and data on actual deaths, injuries, damage and resultant harm documented from any use. Evidence on any persistence of hazards in the environment can also be relevant here.

What type of harm?

A second framing – arguably more direct in its relation to moral authority – is that there are some things that are just not right. New technologies are arguably more amenable to consideration with respect to the type of harm they will cause than the scale of harms that may result from their use. Insofar as the type of harm accords with mechanisms of harm already considered acceptable (e.g. traumatic amputation of limbs due to blast effect), it is unlikely that distinct new concerns can be raised.[35] However, novel mechanisms of harm may tend to provide a basis for distinct concerns to be raised.

In general, whilst harming through kinetic means – punching, striking, puncturing, etc. – may be considered broadly acceptable, other mechanisms of harm – burning, poisoning, irradiating, etc. – are more likely to precipitate concerns. The mechanism through which force is applied can therefore have an impact on assessments of acceptability.

Another way in which types of harms may be categorized relates to the form of impairments that are experienced. Blinding, for example, is a specific cause for concern in the CCW’s protocol on blinding lasers. In this context, as well as in relation to riot-control agents under the CWC, the permanence of effects is considered significant.[36] This raises questions about how other issues of sensory impairment might be considered in the future. Elsewhere, the specific tendency of anti-personnel landmines to cause lower-leg amputation was also considered an issue of concern. The prohibition of weapons that render death inevitable reflects a long-standing concern.[37]

Finally, for the purposes of this list, evidence that a particular mechanism of harm might deliberately or inadvertently have demographically disaggregated effects (e.g. on the basis of a person’s sex or race) has been a consideration in some discussions (which in turn may bear upon assessments of how much harm might occur to whom).[38]

Evidence related to this framing is likely to include medical assessments on the form of harm created in the human body, its impact and its persistence. Whilst the issues discussed here all relate to the human person, types of impact on the environment could also be considered relevant.

What impact on peace and security?

Whilst considerations of scale and type of harm dominate in international humanitarian law (IHL)-oriented discussions around weapons, wider concerns regarding peace and security are occasionally appealed to (e.g. in the debate about armed drones and autonomous weapon systems). Such appeals generally suggest that certain technologies may make conflict more likely, precipitate an ‘arms race’ or negatively affect strategic stability or the perceived balance between offensive and defensive capabilities. Such arguments can be hard to quantify or systematically evidence when it comes to current or future technologies. In previous and ongoing discussions regarding weapons, concerns have been raised in relation to:

- erosion of legal or political distinctions such that modes of behaviour associated with conflict are exported into situations where other expectations of behaviour should predominate (e.g. law enforcement);
- forms of technology that may be so decisive in their advantages that their development by some would demand their development by others in order to maintain political stability;
- technologies that are unpredictable in their functioning such that they may accidentally initiate or escalate a conflict.

The parameters of relevant evidence in this area are more difficult to sketch, but may draw upon examples of practice where the appropriate legal regime is contested, or comparative experience with similar technologies.

Conclusion: Towards a precautionary orientation to science and technology governance with implications for the multilateral control of weapons

New technologies are often greeted, by those called upon to assess their potential benefits and risks, with bewilderment and conflictedness – how to make sense of conflicting bits of information? – between frustration (not knowing what the thing is) and a sense of limitless possibilities and enthusiasm.

To structure policy-making in situations where a new technology brings both the possibility of harm and benefit, as well as scientific uncertainty about the harms and benefits involved, we can attempt to prevent or restrain the activity until cause–effect relations are better understood, or we can promote the activity while learning more about cause–effect relations along the way.

In the sphere of weapons technologies, to date, we have tended to privilege the latter. Developments tend to be assumed to be acceptable unless proven to be ‘illegal’ under the terms of existing law. In environmental protection, public health and other spheres, by contrast, a ‘precautionary’ approach has been employed in situations where risks are foreseen but their full implications are uncertain, and where concrete evidence may be in short supply.

At the heart of a precautionary orientation is a starting assumption that new developments that may present potential harms should be considered unacceptable until proven otherwise. Such an orientation can take different forms, including ‘waiting-with-vigilance for a state of knowledge that may never be forthcoming’, the specification of limits and thresholds and the preventive prohibition of certain actions.

A precautionary orientation to S&T governance with implications for the multilateral control of weapons does not aim to halt or hinder research and scientific progress. Rather, it helps to transform an undecidable and uncertain future into a set of more concrete and better-specified forms. The articulation of particular futures helps to stabilize meaning and identify specific and manageable concerns. This enables decision-making and allocation of particular issues to existing institutions, such as the CCW.

Ultimately, scrutiny of S&T developments is a form of precaution that is consistent with support for science, as it helps to establish the conditions under which science can develop successfully.

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NOTES ON THE 'PRELIMINARY OBSERVATIONS'

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29 In relation to nanotechnologies, see 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, p. 258.
30 E.g., Altmann, 'Preventing Hostile and Malevolent Use of Nanotechnology', p. 68.
31 B. Rappert et al, 'The Roles of Civil Society in the Development of Standards Around New Weapons and Other Technologies of Warfare', 94(886) *International Review of the Red Cross* (2012) 768, https://www.icrc.org/en/doc/assets/files/review/2012/irrc-886-rappert-moyes-crowe-nash.pdf.
32 C. Rehmann-Sutter, 'Which Ethics for (of) the Nanotechnologies?', M. Kaiser et al (eds), *Governing Future Technologies: Nanotechnology and the Rise of an Assessment Regime*, 2010, p. 240.
33 S. Jasanoff, 'Technologies of Humility: Citizen Participation in Governing Science', 41(3) Minerva (September 2003).
34 Gamson and Modigliani cited in B. Rappert et al, 'The Roles of Civil Society in the Development of Standards Around New Weapons and Other Technologies of Warfare', 773.
35 In the late 1990s, the SIrUS project of the International Committee of the Red Cross (ICRC) proposed to use data relating to the effects of 'conventional weapons' – those that cause physical trauma by explosions and projectiles – as a baseline for determining what constitutes superfluous injury or unnecessary suffering (R. M. Coupland (ed.), *The SIrUS Project: Towards a Determination of Which Weapons Cause 'Superfluous Injury or Unnecessary Suffering',* ICRC, 1997, p. 22). See also 'Memorandum for AAC/JAQ (Mr. Luthy) regarding Requested Legal Review of the Massive Ordnance Air Blast (MOAB) Weapon', [US] Department of the Air Force, The Judge Advocate General, 21 March 2003: 'Blast and fragmentation are historic and common anti-personnel effects in lawful military weapons. There are no components that would cause unnecessary suffering.'
36 Art II(7), CWC.
37 1868 St Petersburg Declaration.
38 Whereas indiscriminate harm, indicative of a lack of control over the effects of a weapon, has long been recognized as a key concern in IHL-oriented framings, there appears to be a tendency for some degree of randomness and uncertainty to be preferred over the very specific and very certain. Such a finding is perhaps counter-intuitive, but may suggest that a moral hazard can arise for the user when the effects of a weapon technology on an individual person or category of persons appear so controlled. In relation to autonomous weapon systems, see M. S. Swiatek, 'Intending to Err: The Ethical Challenge of Lethal, Autonomous Systems', 14(4) *Ethics and Information Technology* (2012). Consider also the debate on 'Targeted Killings' (e.g. N. Melzer, *Targeted Killing in International Law*, OUP, 2008).
39 J. B. Holbrook and A. Briggle, 'Knowing and Acting: The Precautionary and Proactionary Principles in Relation to Policy Making', 2(5) *Social Epistemology Review and Reply Collective* (2013) 17, https://socialepistemologydotcom.files.wordpress.com/2013/04/holbrook_briggle_preprint.pdf.
40 Nordmann and Schwarz, 'Lure of the "Yes"', p. 256.

Annex A: Nanoweapons

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This paper was written by Maya Brehm. The author gratefully acknowledges the input of Kobi Leins, who provided comments on an earlier draft.

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 ON ANNEX A

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 subareas 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.

13 According to, Rain Liivoja, Kobi Leins and Tim McCormack, 'no nanotechnology-derived weapons appear to be in production as yet' (R. Liivoja et al, 'Emerging Technologies of Warfare', R. Liivoja and T. McCormack (eds), *Routledge Handbook of the Law of Armed Conflict*, 2016, p. 618). For recent estimates of the time of potential introduction of selected military applications, see Altmann, 'Preventing Hostile and Malevolent Use of Nanotechnology', p. 58.

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.

16 A. Ananthaswamy, 'March of the Motes', *New Scientist*, 23 August 2003; TheNanoAge.com, 'Military Uses of Nanotechnology', http://www.thenanoage.com/military.htm.

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/.

22 M. E. Kosal, 'Anticipating the Biological Proliferation Threat of Nanotechnology: Challenges for International Arms Control Regimes', H. Nasu and R. McLaughlin (eds), *New Technologies and the Law of Armed Conflict,* 2014, p. 163.

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.

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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.

Annex B: Directed Energy Weapons

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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 ON ANNEX B

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.
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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).
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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).
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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).
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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.

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