Article36

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Science, technology and weaponization: preliminary observations

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

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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, new 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. As such this should 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 and Toxin Weapons Convention (BTWC), 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 a 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 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 to ensure 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 weapon 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 that 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 weapon, 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]

Adopting 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 an 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 OPCW assesses and reports on developments in S&T relevant to the Convention.[11] A review of developments in the field of S&T technology related to the BTWC 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) offer various potential military applications. Some are already the subjects of research: imagery analysis using computer vision algorithms for target identification is one example.[16] Potentials for '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 – have also been suggested.[17] Some of these developments are already the subject of deliberations by the CCW's Group of Governmental Experts (GGE) on "Lethal Autonomous Weapons Systems". Among other issues, concerns arise about the exercise of human control and judgment 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 (BCI) 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 faces 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), because they play a central role in state's security policies, and due to 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 bring out 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 longstanding 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 recognised as unacceptable.

Beyond such mandate questions, deciding that certain issues should be a focus for 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 "securitise" it - actually furthering 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 a 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, is it 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 side-step public debate about the goals of science policy and of science policy makers.[28] The public and policy makers are invited to talk and think about emerging technologies on the premise that the nano-world, the AI-world, the enhanced-human-world is 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 the downfall of us all, others are portrayed as bringing an advantage to some states or people at the expense of others or to strengthen national security to the detriment of international peace or human security.[30] There can be a tendency to prioritise 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 not to rule out pathways of technological development which 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 argues in favour of 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, any such mechanism 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 about 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 also 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 may 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 reviewing, and about what orientation should be taken to 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 an issues at stake, of 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 is conceptualized as harms, risks or benefits, and what evidence is needed to assess these. Assessments of acceptability and desirability in multilateral considerations of weapon technologies tend to be presented within 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 conceptualized harms, risks and benefits in novel ways if they are to be considered most appropriately.

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 are these effects (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. 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 categorised 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 that 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 to cause lower leg amputation in the case of anti-personnel landmines was also considered an issue of concern. The prohibition of weapons that render death inevitable reflects a longstanding 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 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 by bewilderment and conflictedness (how to make sense of conflicting bits of information?) between a sense of 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 and 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.[39]

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",[40] 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.

ANNEX 1

Nanoweapons

The authors gratefully acknowledge the input provided by Kobi Leins, whose forthcoming PhD thesis focuses on the legality of nanotechnology-enhanced weapons.

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Nanomaterials have the potential for significant and diverse impacts on human society.[41] 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.[42] Nanomaterials also have potential applications in the military and security sectors. Suggested developments include garments designed to increase soldier survivability[43] and camouflage against thermal detection[44] as well as new weapons and surveillance technologies.[45]

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

- 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 against indiscriminate attacks and superfluous injury or unnecessary suffering, or the prohibition 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 categorisations 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 nano-devices may escape existing verification techniques (e.g. metal-less firearms, miniaturized weapons). This may lead to a loss of trust in the effectiveness of multilateral weapons control regimes in securing international peace and security.

What are nanomaterials?

The prefix ‘nano’ means one thousand millionth of a meter (1nm = 10^{-9} m).[46] 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 to specific ends.[47] This is of interest because at nanoscale (below 100nm)[48] matter exhibits different reactive, optical, electrical and magnetic properties compared to the macroscale.

Nanomaterials also offer profound challenges. Chemical, biological and physical properties merge at the nanoscale, making some traditional regulatory distinctions uncertain. Furthermore, some materials are toxic at nanoscale even if their macro counterparts are not.[49] 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.[50]

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 at the nanoscale, or that cause harmful effects in nanoscale.
Current state of play

Total global, private and public, investment in nanotechnology research and development (R&D) has grown rapidly since the early 1990s,[51] 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.[52]

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, 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).[53]

- Sensors that allow for improved reconnaissance, better sensory capabilities of weapons and munitions,[54] and the detection, reduction and elimination of biological or chemical agents, or trace quantities of explosives;[55]
- Pervasive, distributed nano-scale sensor nets with computational and wireless communication abilities ("smart dust"), potentially as components of an autonomous weapon system;[56]
- Missiles, artillery projectiles or mortar rounds with reduced mass, greater destructive force, increased penetration capability, tailored energy release, smaller size or improved accuracy;[57]
- Lighter and smaller firearms made of nanofibre composites with low or no metal content, and "self-steering" bullets equipped with optical sensors;[58]
- Means of weapon delivery with reduced drag and increased payload and range,[59] nano-enhanced miniaturized munitions, including for UAVs (drones), and nano- and micro combat robots, enabling swarming;[60]
- Improvements in solid-state and electric laser systems making them mobile and readily deployable as a weapon;[61]
- Novel chemicals and biological agents (potentially self-replicating);[62]
- 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;[63]

Possible adverse effects and risks

It has been argued that nanotechnologies may offer "[w]hole new classes of accidents and abuses".[64] Aside from wider social and ethical issues,[65] key military and security concerns regarding the use of nanomaterials include:

- Novel bio-chemical 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.[66] An additional concern relates to the possibility of using genetic markers to target specific groups or individuals.[67]
- Some nano-enhanced technologies may affect strategic stability, for example by giving a distinct advantage to the offense. This may weaken belief in deterrence, raise the risk of escalation and accidental war and lead to an arms race.[68]
- 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,[69] thresholds based on caliber, quantity, size or weight of an item,[70] the distinction between conventional weapons and weapons of mass destruction, and between ammunition/munitions and their means of delivery.[71] The difficulty to detect 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.[72]
- Nanoengineered 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's no need for large production facilities.[73]

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.[74] 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 larger scale, and can complicate their detection and removal from human tissue, the air, water or soil.[75] 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.[76] Risks may be gender- or generationally-differentiated.[77]

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 Biological and Toxin Weapons Convention (BTWC) and the 1993 Chemical Weapons Convention (CWC). Together these instruments ban nanomaterials of known toxic chemicals or biological agents, as well as nano-sized devices designed to deliver them,[78] except where intended for prophylactic, protective or other peaceful purposes.[79] A strong argument can also be made that the legal bans on biological and on chemical weapons extend to nanomaterials with novel properties that affect life processes in ways analogous to known toxic chemicals and pathogens.[80] It has also been argued that using nanoparticles whose physical properties or accumulation in the human body, or nanorobots that are programmed to injure at the cellular level without biochemical action may fall foul of the IHL prohibition on the use of poison and poisoned weapons.[81]

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 primarily injuring by non-detectable fragments,[82] whether miniaturized missiles and similar explosive projectiles runs counter to the prohibition on the use of exploding bullets,[83] whether nano-enhanced lasers raise issues under CCW Protocol IV on blinding laser weapons,[84] whether small armed robots undermine the effectiveness of existing strictures on landmines,[85] 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.[86]

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,[87] as may be the case with nanomaterial-induced health effects. Civilians "enjoy general protection against dangers arising from military operations",[88] which would include, for example, protection from hazardous nanoparticles released into the environment as a result of the degradation of armor 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.[89] Precautions must be taken against such effects, including in the choice of weapons and targets, so as to minimize the danger to civilians.[90]

Additional restrictions derive from states' duties under international human rights and environmental law. Everyone is protected, at all times, against discriminatory targeting practices[91] and acts of genocide,[92] that 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.[93] 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.[94] States should also anticipate that the difficulty to detect nanomaterials or -devices 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,[95] whereas others promote the development of regulations or meta-regulatory tools to "help ensure the technology achieves its potential for good".[96] 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,[97] 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.[98]

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,[99]
- amendments to existing instruments, notably the CWC and the BTWC, or clarification of their provisions,[100]
- clearer guidance and transparency for weapon reviews,[101]
- and the development of guidelines and scientific protocols to promote self-regulation by states and scientific communities.[102]

ANNEX 2

Directed Energy Weapons

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 operationalised, 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"[103] 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 sharp bursts of light to "stun" or disorient people;
- weapons that use electromagnetic (usually radiofrequency) waves including millimetre- or micro-waves 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 to require 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.

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.[104] 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.[105]

Lasers

Long a staple of science fiction, lasers[106] have captured the attention of militaries and policy-makers since Albert Einstein first theorised about the possibility of "stimulated emission" in 1917.[107] 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.

Lasers direct intensely-focussed beams of energy, and are usually powered by a chemical fuel, electric power, or a generated stream of electrons.[108] 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 routinely 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.[109] Such laser weapons, which were designed to cause permanent blindness, were prohibited in 1995 under Protocol IV to the Convention on Certain Conventional Weapons (CCW)[110] before they were widely put to use. Since then, the focus has been on developing 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.[111] They can also, when designed to emit visible light, be used against humans to temporarily blind or disorient.[112]

Lasers have a number of effects on targets which can be used to military advantage: their most basic effect is one of 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 that temporarily blinds or "dazzles". At higher intensities, lasers can create both heat and a mechanical impulse – when used together these properties can cause more extensive damage than when used alone.[113] By heating a target, the beam can deform or melt a hole in it; at even greater intensities, a beam can cause vapourisation which in turn delivers an impulse to the surface of a target,[114] 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.[115]
- Electric-powered and solid-state lasers[116] 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 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).

The recent advent of more portable and relatively cheap laser systems[117] driven by developments in nanotechnology[118], 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[119], 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. But, 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.[120] This has been reflected in the advancement of tests: the U.S. Navy trialled its laser weapons system (LaWS) to shoot down a ScanEagle unmanned aerial vehicle 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 UK and Russia's defence ministries have also reportedly confirmed they are channelling extensive funding towards the development of laser, electromagnetic and plasma weapons.[121]

Electromagnetic radiation technologies

Several militaries are already seeking to weaponise microwave and millimeter-wave radiation[122] 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 U.S. are all reported to be actively pursuing the use of this technology in their military arsenals.[123] 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.[124] It is also reported that the U.S. 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.[125] Other microwave systems have been developed for use against missiles, improvised explosive devices (IEDs), and military vehicles.

Alternatively, electromagnetic radiation weapons (or "microwave weapons") 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 for use 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 China's navy.[126] The best-known example, however, remains the U.S. Active Denial System, a millimetre wave source that produces an intense burning sensation in the skin of targets, 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 weapon might be perceived.[127]

Particle beams

During the Cold War, the U.S. and USSR explored particle-beam weapons for use both on land and in space, but eventually abandoned the research as unfeasible for military application.[128] 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.[129] 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 the 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 limit the damage inflicted.

The technology behind them – particle accelerators[130] – 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 in 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 the earth's atmosphere, they would need an extremely large power supply, and to work in space they would require the ability very precisely to 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.[131] 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".[132]

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 operationalisation remain, but progress is, however, 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, but also wider ranging fields such as nanotechnology and material science. At the same time, other complementary technologies – for example, advanced image-recognition that gives more granular 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, and there is little publicly-available research on the effects of such weapons on humans. Their adverse effects consequently remain largely unknown: 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.[133] Pulsed chemical lasers can produce plasma in front of a target, which then creates a blast wave with subsequent blunt trauma or traumatic amputation of limbs. 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.[134] Electromagnetic radiation weapons can penetrate clothing to heat a person's skin, causing pain and potentially severe burns;[135] particle beam weapons can be expected to produce significant and potentially deadly burns as well as other injuries, including some consistent with ionizing radiation.[136] The one known instance of injury caused by a single hit from higher intensity particle accelerator resulted in the beam burning a hole directly through a physicist's skin, skull and brain. Though through luck he survived (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.[137]

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 of 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 of 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 device (EMP, also known as an "E-bomb") could be devastating, with the potential to cause propagating failures in power, transport and communications networks.[138]

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 which would apply to DEW. These range from national civilian-use regulations and guidelines to international humanitarian 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. DEW are often classified as "non-lethal" or "less-lethal" weapons, with proponents setting them apart from "lethal" weapons.[139] 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[140], suggesting that their potential to cause damage to human health has already been recognised under other 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 microwave weapons), and the prohibition on cruel, inhuman or degrading treatment. Certain DEW are designed to act silently and invisibly – such as microwave weapons, which cause severe pain without necessarily leaving visible marks or physical evidence of their use – making their abuse easy to conceal, 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.[141]

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."[142] 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 International Humanitarian Law (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.[143] Under Article 36 of Additional Protocol I (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.[144]

There is a wide range of IHL provisions which 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.[145] 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,[146] and a strong argument can be made that the Protocol in effect also prohibits the deliberate use of other laser systems to blind.[147] However, the definition of 'permanent blindness' used in the Protocol may not accord with a modern understanding of 'visual impairment'.[148] 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.[149] Despite claims over the accuracy of DEW, questions remain around the ability for certain DEW to be targeted at a specific military objective,[150] in compliance with the IHL rule of distinction and the prohibition of indiscriminate attacks.[151] Potential effects such as burning, eye damage, or radiation sickness may raise concerns under the prohibition of causing superfluous injury or unnecessary suffering.[152] 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.[153]

International environmental law may also be implicated in the use of certain DEW. Protection of the environment during armed conflict is increasingly emphasised as technological developments in new weaponry present new threats to the natural world.[154] The UN Environment Assembly in May 2016 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 the 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 international humanitarian law 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 recognised, 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.

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[3] E.g. OPCW, Report of the Scientific Advisory Board, UN doc SAB-26/1, 20 October 2017, §10.
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[6] 1868 Declaration Renouncing the Use, in Time of War, of Explosive Projectiles Under 400 Grammes Weight.
[7] UN doc CCW/CONF.V/WP.4.
[8] UN doc CCW/CONF.V/10.
[9] UN doc A/C.1/72/L.52/Rev.1, 26 October 2017.
[10] http://www.article36.org/processes-and-policy/ccw/sci-tech-intro.
[11] https://www.opcw.org/about-opcw/subsidiary-bodies/scientific-advisory-board/. States parties to the CWC have determined that the Convention's definition of a chemical weapon adequately covers these developments. (UN doc RC-1/5, 9 May 2003, § 7.23.)
[12] UN doc BWC/CONF.VII/7, §2.
[13] A. Moodie, 'Reforming the Biological and Toxin Weapons Convention's S&T Review Process', The Bifurcated Needle, 16 May 2016.
[14] 'Strengthening the BWC Science and Technology Review Process: Considerations Regarding the Composition of an S&T Review Body', Submission by Switzerland to the Preparatory Committee for the Eighth Review Conference, August 2016. States parties to the BTWC have also reached an understanding that Article I of the Convention applies to all scientific and technological developments in the life sciences and in other fields of science relevant to the Convention. (For a summary, see 'Additional Agreements Reached by Previous Review Conferences Relating to Each Article of the Convention', BWC Implementation Support Unit, UNODA, February 2012, §§13-16.)
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[22] Nuffield Council on Bioethics, 'Novel Neurotechnologies: Intervening in the Brain', op cit. See also Royal Society, 'Brain Waves Module 3: Neuroscience, conflict and security', 2012.
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[24] In relation to nanotechnologies, see M. Schillmeier, 'What ELSA/I Makes Big and Small in Nanotechnology Research', in B. Rappert and B. Balmer, Absence in Science, Security and Policy, 2015, p 63.
[25] J. Schummer, 'From Nano-Convergence to NBIC-Convergence: "The Best Way to Predict the Future is to Create it"', in M. Kaiser et al (Eds), Governing Future Technologies: Nanotechnology and the Rise of an Assessment Regime, op cit, p 57.
[26] See, e.g., 'Methodology', Envisioning.
[27] J. Schummer, 'From Nano-Convergence to NBIC-Convergence: "The Best Way to Predict the Future is to Create it"', op cit, p 61.
[28] Ibid, observing that the human ideal that convergence promises to realize is modeled after the perfect warfighter, Schummer

concludes that "The convergence-as-opportunity talk" succeeded in passing off "the specific interests of the military and transhumanists as the proper goals of the society at large." (Ibid, p 67.)

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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) p 768.

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33 S. Jasanoff, 'Technologies of Humility: Citizen Participation in Governing Science', 41 Minerva (2003) 223-244.

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', op cit, p 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', [U.S.] 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, have 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) pp 241–254. 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) p 17.

40 A. Nordmann and A. Schwarz, 'Lure of the "Yes"', op cit, p 256.

41 E.g., The Royal Society and The Royal Academy of Engineering, 'Nanoscience and Nanotechnologies: Opportunities and Uncertainties', July 2004, p 5; M. C. Roco and W. S. Bainbridge, 'Societal Implications of Nanoscience and Nanotechnology', NSET Workshop Report, National Science Foundation, 2001, p 3. 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', in H. A. M. J. ten Have (Ed), Nanotechnologies, Ethics and Politics, UNESCO, 2007, p 87.

42 See, e.g., the Inventories of the Project on Emerging Nanotechnologies at http://www.nanotechproject.org/inventories.

43 'U.S. Scientists Design Smart Underpants that could Save Lives', Reuters, 10 June 2010.

44 B. Kim et al., 'Patternable PEDOT Nanofilms with Grid Electrodes for Transparent Electrochromic Devices Targeting Thermal Camouflage', 2(19) Nano Convergence (2015).

45 In particular, J. Altmann, Military Nanotechnology: Potential Applications and Preventive Arms Control, Contemporary Security Studies, Routledge, 2006, chapter 4.

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48 'ISO TC 229: Nanotechnologies', International Organization for Standardization, https://www.iso.org/committee/381983.html. Although "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.)

49 According to Schummer, "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". ('Identifying Ethical Issues of Nanotechnologies', op cit, p 85.)

50 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 and Science 20 (2009/2010) p 21.

51 Several indicators can be used to assess research and development in nanotechnologies, for example the number of patent filings, the development of sub-areas or the number of citations. See e.g., M. C. Roco, C. A. Mirkin, and M. C. Hersam (Eds.), Nanotechnology Research Directions for Societal Needs in 2020: Retrospective and Outlook, Springer, 2010, xlii–xlvi. For data, see, 'Tapping nanotechnology's potential to shape the next production revolution', in The Next Production Revolution: Implications for Governments and Business, OECD, 2017.

52 For a recent overview, see Altmann, 'Preventing Hostile and Malevolent Use of Nanotechnology Military Nanotechnology After 15 Years of the US National Nanotechnology Initiative', op cit, 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. ; M. Berger, 'Military Nanotechnology - How Worried Should we be?', Nanowerk, 13 November 2006.

[53] According to, R. Liivoja, K. Leins and T. McCormack, 'Emerging Technologies of Warfare', in R. Liivoja and T. McCormack (Eds), Routledge Handbook of the Law of Armed Conflict, Routledge, 2016, p 618, "no nanotechnology-derived weapons appear to be in production as yet". For recent estimates of the time of potential introduction of selected military applications, see J. Altmann, 'Preventing Hostile and Malevolent Use of Nanotechnology Military Nanotechnology After 15 Years of the US National Nanotechnology Initiative', op cit, p 58.

[54] H. Paschen et al., 'Nanotechnology (Summary)', Working report, Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag (TAB), July 2003, p 7.

[55] N. Pala and A. N. Abbas, 'Terahertz Technology for Nano Applications', in B. Bhushan (Ed), Encyclopedia of Nanotechnology, Springer, 2016, p 4070; M. Sadeghi, S. Yekta and H. Ghaedi, 'Decontamination of Chemical Warfare Sulfur Mustard Agent Simulant by ZnO Nanoparticles', 6(3) International Nano Letters (2016) pp 161–71.

[56] A. Ananthaswamy, 'March of the Motes', New Scientist, 23 August 2003; 'Military Uses of Nanotechnology', The Nano Age, http://www.thenanoage.com/military.htm.

[57] E.g., J. Altmann and M. Gubrud, 'Anticipating Military Nanotechnology', IEEE Technology and Society Magazine, Winter 2004, pp 33–40; Paschen et al., 'Nanotechnology (Summary)', op cit; 'US Air Force Invests in Western New York Technology; Grants NanoDynamics™ Contract for Nanostructured Tantalum', Nano Tsunami, 29 August 2005.

[58] Altmann, Military Nanotechnology: Potential Applications and Preventive Arms Control, op cit, p 85; T. Lewis, 'US Military's Self-Steering Bullets Can Hit Moving Targets', Live Science, 28 April 2015.

[59] E.g., A. Lang, M. L. Habegger and P. Motta, 'Shark Skin Drag Reduction', in B. Bhushan (Ed), Encyclopedia of Nanotechnology, Springer, 2016, p 3639.

[60] Altmann, Military Nanotechnology: Potential Applications and Preventive Arms Control, op cit, pp 93–95; Altmann and Gubrud, 'Anticipating Military Nanotechnology', op cit, p 36. On nanorobotics, generally, see S. Tsuda, 'Nanorobotics', in B. Bhushan (Ed), Encyclopedia of Nanotechnology, Springer, 2016, pp 2641–45.

[61] H. Nasu, 'The Future of Nanotechnology in Warfare', The Global Journal, 4 July 2013.

[62] M. E. Kosal, 'Anticipating the Biological Proliferation Threat of Nanotechnology: Challenges for International Arms Control Regimes', in H. Nasu and R. McLaughlin (Eds), New Technologies and the Law of Armed Conflict, T.M.C. Asser Press, pp 2014, 163.

[63] J. Thorpe, K. Girling and A. Auger, '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; K. Leins, 'Shining a Regulatory Spotlight on New Lasers: Regulation of the Use of Nanolaser Technologies in Armed Conflict', Jurimetrics, Spring 2016, pp 266–268; P. Tucker, 'A Breakthrough in the Checkered History Of Brain Hacking', Defense One, 1 July 2014,.

[64] The Royal Society and The Royal Academy of Engineering, 'Nanoscience and Nanotechnologies: Opportunities and Uncertainties', op cit, §28.

[65] 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 , Report of the IBC on the Principle of Non-Discrimination and Non-Stigmatization, 3 June 2014, p 25.)

[66] J. Altmann, Military Nanotechnology: Potential Applications and Preventive Arms Control, op cit, pp 101–103; 'Nanotechnology Paves Way for New Weapons', Jane's Chem-Bio Web, 27 July 2005; Kosal, 'Anticipating the Biological Proliferation Threat of Nanotechnology: Challenges for International Arms Control Regimes', op cit; A. Gsponer, 'From the Lab to the Battlefield? Nanotechnology and Fourth-Generation Nuclear Weapons', Disarmament Diplomacy, no. 67 (November 2002), http://www.acronym.org.uk/old/archive/dd/dd67/67op1.htm.

[67] Altmann and Gubrud, 'Anticipating Military Nanotechnology', 36; Leins, 'Regulation of the Use of Nanotechnology in Armed Conflict', op cit p 47; M. Wheelis, 'Will the New Biology Lead to New Weapons?', Arms Control Today, July 2004.

[68] Altmann and Gubrud, 'Anticipating Military Nanotechnology', op cit, p 38; M. E. Kosal, 'Military Applications of Nanotechnology: Implications for Strategic Security I', PASCC Final Report, Sam Nunn School of International Affairs, Georgia Institute of Technology, 2014, p 65.

[69] Nanomaterials can be used to induce changes in the human body that challenge the bans on blinding laser weapons, biological and chemical weapons. See Leins, 'Shining a Regulatory Spotlight on New Lasers…', op cit.

[70] 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', op cit, p 36.

[71] See e.g. M. Bolton and W. Zwijnenburg, 'Futureproofing Is Never Complete: Ensuring the Arms Trade Treaty Keeps Pace with New Weapons Technology', Working paper, ICRAC, October 2013, p 4.

[72] 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) pp 283–297.

[73] The Royal Society and The Royal Academy of Engineering, 'Nanoscience and Nanotechnologies: Opportunities and Uncertainties', op cit, §28.

[74] Schillmeier, 'What ELSA/I Makes Big and Small in Nanotechnology Research', op cit, p 63.

[75] International Bioethics Committee , Report of the IBC on the Principle of Non-Discrimination and Non-Stigmatization, p 25.

[76] N. A. Lewinski, 'Nanoparticle Cytotoxicity', in B. Bhushan (Ed), Encyclopedia of Nanotechnology, Springer, 2016, pp 2546-2555; F. Nesslany and L. Benameur, 'Genotoxicity of Nanoparticles', in B. Bhushan (Ed), Encyclopedia of Nanotechnology, Springer, 2016, pp 1328–1338.

[77] 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', in B. Bhushan (Ed), Encyclopedia of Nanotechnology, Springer, 2016, pp 4317–4324), and it has been argued that "Children 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 Futur , Nano - The Great Unknown, Position Paper, February 2012, p 2.)

[78] 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 33 (2009) pp 860–61.

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

[80] For a detailed discussion, see Wallach, 'A Tiny Problem with Huge Implications …', op cit, who also raises the question whether the CWC and the BTWC prohibit the development and use of engineered viruses or nanorobots.

[81] ICRC, Customary IHL Database (ICRC CIHL 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, Leins and McCormack, 'Emerging Technologies of Warfare', op cit, p 619.

[82] 1980 CCW Protocol I. A recent Danish military manual mentions nanotechnology in relation to that prohibition (Militærmanual om folkeret for danske vaebnede styrker i internationale militaere operationer, 2016, section 3.10). For a discussion, see Nasu and Faunce, 'Nanotechnology and the International Law of Weaponry …', op cit, p 22. Note, however, that some states consider that prohibited covers only weapons whose "primary effect" is to injure by non-detectable 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 CIHL study, Rule 79.) It is also questionable whether nanoparticles can be likened to "fragments".

[83] 1868 St. Petersburg Declaration; ICRC CIHL study, Rule 78.

[84] 1995 CCW Protocol IV; ICRC CIHL study, Rule 86.

[85] 1996 Revised CCW Protocol II, 1997 Anti-Personnel Mine Ban Convention; See, Altmann, 'Preventing Hostile and Malevolent Use of Nanotechnology Military Nanotechnology After 15 Years of the US National Nanotechnology Initiative', op cit, p 64.

[86] 1996 Revised CCW Protocol II; ICRC CIHL study, Rule 80. See, Wallach, 'A Tiny Problem with Huge Implications …', op cit, p 934.

[87] ICRC CIHL 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".

[88] Art 51(1), API; See also ICRC CIHL study, Rule 15.

[89] Art 51(4) API; ICRC CIHL Rules 1, 17, 71.

[90] Art 57(2)(a)(ii) and (3), API; ICRC CIHL study, Rules 15, 17, 18, 19 and 21.

[91] Art 26, ICCPR; Art 2, CEDAW; Art 2, CERD; Art 6, Universal Declaration on the Human Genome and Human Rights; Art 11, Council of Europe Convention on Human Rights and Biomedicine 164.

[92] Art 1, 1949 Convention on the Prevention and Punishment of the Crime of Genocide.

[93] Art 6, ICCPR ; Arts 11 and 12, ICESCR.

[94] Art 17, ICCPR.

[95] Women in Europe for a Common Futur , Nano - The Great Unknown op cit, p 3.

[96] 'Information on the Responsible Nano Code Initiative', Responsible Nanotechnologies Code Working Group, May 2008. See also Precautionary Matrix for Synthetic Nanomaterials, version 3.0, Swiss Federal Office of Public Health, 2013; European Commission Recommendation on a Code of Conduct for Responsible Nanosciences and Nanotechnologies Research and Council Conclusions on Responsible Nanosciences and Nanotechnologies Research, 2009.

[97] Art 36, API.

[98] For example, 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', Environmental Science & Technology, 15 May 2017.

[99] Altmann makes detailed recommendations for preventive arms control (J. Altmann, 'Nanotechnology and Preventive Arms Control', Deutsche Stiftung Friedensforschung, 2005); 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?', op cit); 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)); See also Pinson, 'Is Nanotechnology Prohibited by the Biological and Chemical Weapons Conventions?', op cit.

[100] E.g. Wallach, 'A Tiny Problem with Huge Implications …', op cit, pp 861, 954.

[101] E.g., Nasu and Faunce, 'Nanotechnology and the International Law of Weaponry: …', op cit, p 54.

[102] Ibidem.

[103] Joint Publication 1-02, Department of Defense Dictionary of Military and Associated Terms, 8 November 2010, p 70.

[104] These include: nanotechnology; material science; battery and energy delivery; greater computing power; better understanding of the variables that influence the use of DEW in the Earth's atmosphere; and adaptive optics.

[105] J. D. Ellis, 'Directed-Energy Weapons: Promise and Prospects', CNAS, April 2015, p 4. Though a fully-developed and fielded DEW offers 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 U.S. Office of the Assistant Secretary of Defence for Research and Engineering/Research Directorate, the U.S. Department of Defence has invested over $6 billion in directed energy science and technology initiatives, (M. Gunzinger and C. Daugherty, Changing the Game: The promise of Directed-Energy Weapons, Center for Strategic and Budgetary Assessments, 2012. In January 2017, the UK reportedly awarded a £30m 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). The U.S. 2017 Defence Bill also reportedly authorised some $328 million for the development and procurement of directed energy weapons (S. Snow, 'Congress Oks more Money, gets Serious about Laser Weapons in Defence Bill', Military Times, 28 December 2016).

[106] An acronym for Light Amplification and Stimulated Emission of Radiation.

[107] E. Tretkoff, 'Einstein Predicts Stimulated Emission', APS News, August/September 2005.

[108] Chemical lasers have historically succeeded in introducing 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. More recently, free-electron lasers have garnered interest due to their ability to circumvent some of the technical challenges that have hampered attempts to operationalise other types of lasers.
[109] In 1995, Human Rights Watch reported that the U.S., China, Russia, Israel and several European states were developing blinding laser weapons. (Human Rights Watch, U.S. Blinding Laser Weapons, 1995.)
[110] 1995 CCW Protocol IV prohibits the use of blinding laser weapons, as well as their transfer to any state or non-state actor.
[111] Russia's Sokol Eshelon project is reportedly working to develop a laser to blind the sensors of an enemy satellite. ('Russia Developing Plane With New-Generation Laser Weapon', TASS, 8 September 2016.)
[112] One example is the "PHaSR", developed by the U.S. Air Force to stun or "dazzle" a target (Personnel Halting and Stimulation Response (PHaSR), United Stats Air Force, Fact Sheet, April 2006).
[113] P. E Nielsen, Effects of Directed Energy Weapons, Directed Energy Professional Society, 2009, p 170.
[114] "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". P. E Neilsen, Effects of Directed Energy Weapons, Directed Energy Professional Society, op cit, p 175.
[115] D. Pudo and J. Galuga, 'High Energy Laser Weapon Systems: Evolution, Analysis and Perspectives', 17(3) Canadian Military Journal (2017).
[116] These include optical fibre lasers like the U.S. Navy's "LaWS".
[117] 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 (27 May 2015).
[118] H. Nasu, 'The Future of Nanotechnology in Warfare', The Global Journal, 4 July 2013.
[119] For example, to destroy an anti-ship cruise missile, a laser would require a beam of 500kw and demand megawatts of power. (A. Robinson, 'Directed Energy Weapons: Will They Ever be Ready?', National Defense, 1 July 2015.)
[120] A recent report set the "cost-per-kill" at about $30 for a "pre-prototype" laser-equipped vehicle designed to target drones and missiles (J. Kester, 'Army, Defence Companies Making Renewed Push for Laser Weapons', Foreign Policy, 12 Oct 2017). See also, [UK] Defence Science and Technology Laboratory, 'Dragonfire: Laser Directed Energy Weapons', Press release, 12 Sept 2017.
[121] T. Batchelor, 'Russia developing laser, electromagnetic and plasma weapons, Kremlin says', Independent, 22 January 2017. The UK is reportedly aiming to develop a ship-mounted laser cannon by 2020 (E. MacAskill, 'Royal Navy aims to put Laser Weapon on Ships by 2020', The Guardian, 15 September 2015).
[122] Microwaves are a band of radiofrequencies in the electromagnetic spectrum ranging in frequency from 300MHz to 300GHz with a wavelength ranging from 100cm to 0.1cm. This includes millimetre waves, electromagnetic radiation in the frequency range of 30GHz to 300GHz with a wavelength in the 10mm to 1mm range.
[123] B. Gertz, 'Report: China Building Electromagnetic Pulse Weapons for use Against U.S. Carriers', The Washington Times, 21 July 2011; A. Withnall, 'Russia Demonstrates First "Microwave Gun" that can Disable Drones and Missiles from up to Six Miles Away at Army-2015', Independent, 16 June 2016.
[124] J. Lin and P. W. Singer, 'China's new Microwave Weapon can Disable Missiles and Paralyze Tanks', Popular Science, 26 January 2017.
[125] 'CHAMP – Lights out', Boeing, 22 Oct 2012.
[126] A. Griffin, 'China Reveals Long-Range Heat Ray Gun', Independent, 15 December 2014.
[127] The Active Denial System: Obstacles and Promise, The Project on International Peace and Security (PIPS), The College of William and Mary, April 2013, p 7.
[128] A. Kochems and A. Gudgel, 'The Viability of Directed-Energy Weapons', The Heritage Foundation, April 2006.
[129] R. M. Roberds, 'Introducing the Particle-Beam Weapon', Air University Review, July-August 1984.
[130] The best-known use of a particle accelerator is in the Large Hadron Collider at CERN (the European Organisation for Nuclear Research) which aimed to create Higgs Boson particles in order to study them.
[131] A. K. Maini, 'Particle Beam Weapons: Technology Areas, Advantages and Limitations', Electronicsforu.com, 13 September 2016.
[132] Ibid.
[133] B Anderberg and M. L. Wolbarsht, 'Laser Weapons: The Dawn of a new Military Age', 2013, p 81.
[134] W. Knight, 'US Military sets PHASRs to Stun', New Scientist, 7 November 2005.
[135] J. Altmann, 'Millimetre Waves, Lasers, Acoustics for Non-Lethal Weapons? Physics Analyses and Inferences', Deutsche Stiftung Friedensforschung, 2008, p 18. For an independent review of the health effects of the ADS in particular, see J. M. Kenny et al, 'A Narrative Summary and Independent Assessment of the Active Denial System', Penn State Applied Research Laboratory, 2008.
[136] 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.
[137] 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. Frohlich, 'What Happens if you Stick your Head in a Particle Accelerator?', The Atlantic, 12 January 2017; 'The Future Ruins of the Nuclear Age', Wired, 1 December 1997.
[138] A report by the U.S. Commission established to assess the threat posed by an EMP attack concluded that the U.S. would suffer "long-term, catastrophic consequences" due to societal dependence on the electrical power system and overall vulnerability to attack. (J. S. Foster et al, Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Electromagnetic Pulse Commission, April 2008.)
[139] Both enthusiasm and concerns over DEW have fallen under a larger debate about the viability and role 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 should be modified or discarded with regard to these weapons; opponents countered that they must comply with existing international law. For an overview, see, e.g., 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) pp 525-552; N. Lewer and M. Davison, Bradford Non-Lethal Weapons Research Project, Research Report No. 7, May 2005.

[140] For example, in the U.S. 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 minimise the risks of exposure

[141] The U.S. Active Denial System uses 1.5m wide beams of mm waves that range up to 1000ft. It is unclear if this width is variable, or if it is adhered to in other millimeter-wave systems. 'Active Denial System FAQs', Non-Lethal Weapons Program, U.S. Department of Defence.

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

[143] Art 35(1), API.

[144] Art 36, API.

[145] 1995 CCW Protocol (IV) on Blinding Laser Weapons. The prohibition is considered by the ICRC to be a norm of customary international law applicable in both international and non-international armed conflicts. (ICRC CIHL Study, Rule 86.)

[146] Art 2, 1995 CCW Protocol IV.

[147] ICRC, CIHL Study, Rule 86.

[148] See WHO, 'Change the Definition of Blindness', International Classification of Diseases Updated and Revision Platform, n.d.

[149] Final Declaration, Review Conference of the States Parties to the CCW, Final Report, Geneva, 1996, UN Doc. CCW/CONF.I/16(PartI), Annex C. For more information, see 'Blinding Laser Weapons', Weapons Law Encyclopedia.

[150] For example, 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 variants, raises significant concerns over military effectiveness and harm to civilians. See, for example, P. Sprangle et al, 'High-Power Lasers for Directed-Energy Applications', 54(31) Applied Optics (2015) pp F201-F209. Complex and challenging operational environments can be expected to exacerbate the inherent difficulties in the operation of DEW, as well as rendering their maintenance logistically more difficult. (D. H. Titterton, Military Laser Technology and Systems, Artech House, 2015, pp 60-61.)

[151] Art 51(4), API; ICRC CIHL Study, Rules 11 and 71.

[152] Art 35(2) API; ICRC CIHL Study, Rule 70.

[153] Arts 51(5)(b) and 57(2)(a)(iii), API ; ICRC CIHL Study, Rules 14 and 15.

[154] See the International Law Commission's set of draft principles on protection of the environment in relation to armed conflict (UN doc A/71/10); UNEP, 'Protecting the environment during armed conflict: An Inventory and Analysis of International Law', 2009.