DISCUSSION PAPER | NOVEMBER 2017

Article36

Directed Energy Weapons

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

Geneva, November 2017

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

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

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

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

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

- Certain DEW may have the potential to circumvent existing legal restrictions and prohibitions on weapons, such as the prohibition on blinding laser weapons, creating comparable effects to prohibited systems but without falling within their technical definitions.
- Traditional interpretations of protective principles, including the prohibition on causing superfluous injury or unnecessary suffering to combatants, may be challenged by novel ways of inflicting physical and mental harm. Historically, systems that harm subjects through non-kinetic means have often been considered an issue of concern or as requiring special consideration.
- There appears to be little public data and considerable uncertainty about the environmental and health effects of DEW.
- Some DEW are promoted for use in various settings and for diverse purposes, which risks further blurring the boundary between law enforcement and war fighting, which traditionally have been subject to different normative regimes.

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

- monitor research and development of DEW and assess their potential to challenge existing restrictions and prohibitions on weapons, or impact national and human security, peace and international security, arms control and disarmament;
- ensure respect for the letter and the spirit of the CCW and its protocols, reaffirm core values and long-standing principles these instruments give expression to and assess the conformity of novel mechanisms of harm with the prohibition on causing superfluous

injury and unnecessary suffering, and the principle of distinction;

- reaffirm the prohibition on blinding laser weapons and assess whether CCW Protocol IV provides adequate protection against blinding in light of the risk to eyesight posed by developments in laser technologies and the evolving understanding of blindness;
- encourage transparency and integrate consideration of DEW in ongoing work, including in relation to weapons reviews in line with Article 36 of Additional Protocol I to the Geneva Conventions (API), ensure that a precautionary approach is applied and that assessments of environmental impact reflect the contemporary understanding of environmental law and protection.

Current state of play

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

Lasers

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

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

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

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

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

- Chemical lasers are fuelled by a potentially toxic mix of chemicals that requires complex logistics to handle and transport, and which carries significant environmental and health risks.[13]
- Electric-powered and solid-state lasers[14] are more stable and more easily transported, but are currently not very efficient as much of the energy required to produce a stable laser beam is lost as heat. Those working to further develop such lasers have struggled to develop sufficient cooling mechanisms to counteract this, though progress is being made.
- Free-electron lasers use a stream of electrons that passes through alternating magnetic fields to generate megawatt laser beams. They avoid both the difficulties of using chemical fuels (as in chemical lasers) and the issue of heat generation (as in electric and solid-state lasers), but they would be very big.

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

Microwave and millimetre-wave radiation technologies

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

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

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

Particle beams

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

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

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

Adverse effects and risks

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

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

There is little publicly available research on the anticipated psychological effects of DEW. They are likely to vary depending on individual vulnerability and state of health, the nature of the target and the context – for example, whether such weapons are used for policing a crowd in the open, in a confined space or in a battlefield situation

– and the degree to which those people affected by the weapons understand what is happening and have training in how to anticipate and counter their effects. Electromagnetic radiation weapons have, to date, reportedly only been tested on trained soldiers; how civilians will react to the sensation of intolerable heating of the skin or to the disorienting effect of 'dazzler' lasers is unknown, but it is not unlikely that the use of such weapons against civilians or forces unfamiliar with them would cause significant panic and perhaps subsequent injury. It is also likely that the use of invisible 'rays' as a mechanism for causing harm would raise ethical and political concerns in some societies.

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

Governance and regulation

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

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

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

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

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

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

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

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

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

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

END NOTES

1 Joint Publication 1-02, 8 November 2010, p. 68, https://fas.org/irp/doddir/dod/jp1_02.pdf.
2 These include: nanotechnology, materials science, battery and energy delivery, greater computing power, better understanding of the variables that influence the use of DEW in Earth's atmosphere and adaptive optics.
3 J. D. Ellis, *Directed-Energy Weapons: Promise and Prospects*, Center for a New American Security, April 2015, p. 4, https://www.cnas.org/publications/reports/directed-energy-weapons-promise-and-prospects. Though fully developed and fielded DEW offer a significant reduction in costs when compared to their kinetic counterparts – a shot from a laser is significantly cheaper than a missile – their development thus far has proven incredibly costly, and significantly more investment would be needed in order to make them fully operational and combat-ready. It is unclear to what degree states will see these costs as a worthwhile investment. According to an estimate from the US Office of the Assistant Secretary of Defense for Research and Engineering/Research Directorate, the US Department of Defense has, since 1960, invested over $6 billion in directed energy science and technology initiatives (Center for Strategic and Budgetary Assessments, *Changing the Game: The Promise of Directed-Energy Weapons*, 2012, p.48, https://csbaonline.org/uploads/documents/CSBA_ChangingTheGame_ereader.pdf). In January 2017, the UK reportedly awarded a £30 million contract to a consortium of European defence firms to produce a prototype laser weapon (P. Rincon, 'UK Military to Build Prototype Laser Weapon', *BBC News*, 5 January 2017, https://www.bbc.co.uk/news/science-environment-38510344). The US 2017 Defense Bill also reportedly authorized some $328 million for the development and procurement of directed energy weapons (S. Snow, 'Congress OKs More Money, Gets Serious About Laser Weapons in Defense Bill', *Military Times*, 28 December 2016 https://www.militarytimes.com/news/pentagon-congress/2016/12/28/congress-oks-more-money-gets-serious-about-laser-weapons-in-defense-bill/). Full text of bill available at https://www.govtrack.us/congress/bills/114/s2943/text.
4 The term 'laser' was originally an acronym for Light Amplification and Stimulated Emission of Radiation.
5 'Einstein Predicts Stimulated Emission', 14(8) *APS News*, (August/September 2005), https://www.aps.org/publications/apsnews/200508/history.cfm.
6 Chemical lasers have historically succeeded in producing megawatt-level outputs, but they are unwieldy and logistically difficult to transport and use. In recent decades, there has been a shift in focus to solid-state lasers, which are often more portable and fuel efficient; they are, rather, in the kilowatts to tens-of-kilowatts class. More recently, free-electron lasers – usually very large and immobile – have garnered interest due to their ability to circumvent some of the technical challenges that have hampered attempts to operationalize other types of lasers.
7 In 1995, Human Rights Watch (HRW) reported that the US, China, Russia, Israel and several European states were developing blinding laser weapons (HRW, *United States: U.S. Blinding Laser Weapons*, Human Rights Watch Arms Project, https://www.hrw.org/reports/1995/Us2.htm.
8 Protocol IV to the 1980 Convention on Certain Conventional Weapons (CCW) prohibits the use of blinding laser weapons as a means or method of warfare, as well as their transfer to any state or non-state actor.
9 Russia's Sokol Eshelon project is reportedly working to develop a laser to blind the sensors of an enemy satellite (D. Cenciotti, 'Russia Has Completed Ground Tests of Its High-Energy Airborne Combat Laser', *Business Insider*, 5 October 2016, https://www.businessinsider.com/russia-high-energy-airborne-combat-laser-system-2016-10?r=UK).
10 One example is the PHaSR (Personnel Halting and Simulation Response) developed by the US Air Force and designed to stun or 'dazzle' a target (E. D. Blaylock, 'New Technology "Dazzles" Aggressors', U.S. Air Force, 2 November 2005, https://archive.is/20120721195102/http:/www.af.mil/news/story.asp?storyID=123012699).
11 P. E. Nielsen, *Effects of Directed Energy Weapons*, 2009, p. 170.
12 'Mechanical effects result when momentum is transferred to a target by vapor shooting from it. In effect, the vapor serves as a small jet, and exerts a reaction force back on the target' (ibid, p. 175).
13 D. Pudo and J. Galuga, 'High Energy Laser Weapon Systems: Evolution, Analysis and Perspectives', 17(3) *Canadian Military Journal* (2017), http://www.journal.forces.gc.ca/Vol17/no3/PDF/CMJ173Ep53.pdf.
14 These include optical fibre lasers like the US Navy's LaWS.
15 Solid-state lasers use rods, slabs or discs of crystal to produce the beam, whereas fibre lasers use thin optical fibres that are lightweight and more compact (A. Extance, 'Military Technology: Laser Weapons Get Real', 521(7553) *Nature* (May 2015), https://www.nature.com/news/military-technology-laser-weapons-get-real-1.17613).
16 H. Nasu, 'The Future of Nanotechnology in Warfare', *The Global Journal*, 4 July 2013, http://www.theglobaljournal.net/article/view/1132/.
17 E.g., to destroy an anti-ship cruise missile, a laser would require a beam of 500 kW and demand megawatts of power (A. Robinson, 'Directed Energy Weapons: Will They Ever Be Ready?', *National Defense*, 1 July 2015, http://www.nationaldefensemagazine.org/articles/2015/7/1/2015july-directed-energy-weapons-will-they-ever-be-ready).
18 A recent report set the 'cost per kill' at about $30 for a 'pre-prototype' laser-equipped vehicle designed to target drones and missiles (J. Kester, 'Army, Defense Companies Making Renewed Push for Laser Weapons', *Foreign Policy*, 12 Oct 2017, https://foreignpolicy.com/2017/10/12/army-defense-companies-making-renewed-push-for-laser-weapons/). See also UK Defence Science and Technology Laboratory, 'Dragonfire: Laser Directed Energy Weapons', press release, 13 September 2017, https://www.gov.uk/government/news/dragonfire-laser-directed-energy-weapons.
19 T. Batchelor, 'Russia Developing Laser, Electromagnetic and Plasma Weapons, Kremlin Says', *Independent*, 22 January 2017, https://www.independent.co.uk/news/world/europe/russia-laser-electromagnetic-plasma-weapons-military-kremlin-a7540716.html. The UK is reportedly aiming to develop a ship-mounted laser cannon by 2020 (E. MacAskill, 'Royal Navy Aims to Put Laser Weapon on Ships by 2020', The Guardian, 15 September 2015, https://www.theguardian.com/uk-news/2015/sep/15/royal-navy-death-ray-laser-cannon-ships-2020; UK Defence Science and Technology Laboratory, 'Dragonfire'.
20 Microwaves are a band of radio frequencies in the electromagnetic spectrum ranging in frequency from 300 MHz to 300 GHz with a wavelength ranging from 100 cm to 0.1 cm. This includes millimetre waves, electromagnetic radiation in the frequency range of 30 GHz to 300 GHz with a wavelength in the 10 mm to 1 mm range.
21 B. Gertz, 'Report: China Building Electromagnetic Pulse Weapons for Use Against U.S. Carriers', *The Washington Times*, 21 July 2011, https://www.washingtontimes.com/news/2011/jul/21/beijing-develops-radiation-weapons/; A. Withnall, 'Russia Demonstrates First "Microwave Gun" That Can Disable Drones and Missiles From up to Six Miles Away at Army-2015', *Independent*, 16 June 2016, https://www.independent.co.uk/news/world/europe/russia-demonstrates-its-first-microwave-gun-that-can-disable-drones-and-missiles-from-up-to-six-10323243.html.
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27 R. M. Roberds, 'Introducing the Particle-Beam Weapon', *Air University Review*, July–August 1984, https://www.bibliotecapleyades.net/scalar_tech/devvision/devvission-appendix-j.pdf.
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CERN, which aimed to create Higgs Boson particles in order to study them.

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30 Ibid.

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

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

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

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

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

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

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

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

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

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

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

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

43 Art 35(1), API.

44 Art 36, API.

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

46 Art 2, 1995 CCW Protocol IV.

47 ICRC, Customary IHL study, Rule 86.

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

49 Final Declaration of the Review Conference, Review Conference of the States Parties to the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons which may be Deemed to be Excessively Injurious or to Have Indiscriminate Effects, Final Report, UN doc CCW/CONF.I/16(Part I), Annex C, 1996. For more information, see 'Blinding Laser Weapons', *Weapons Law Encyclopedia*, http://www.weaponslaw.org/weapons/blinding-laser-weapons.

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

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

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

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

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

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