Abstract
The introduction of nanotechnology into our civil life and warfare is expected to influence the application and interpretation of the existing rules of international humanitarian law. This article examines the challenges posed to international humanitarian law by the widespread use of nanotechnology in light of four basic rules of international humanitarian law: (1) the obligation to ensure the legality of weapons; (2) distinction; (3) proportionality; and (4) precaution. It concludes by identifying three areas of concern, which arise from widespread use of nanotechnology, for the application of international humanitarian law.

Keywords: nanotechnology, superfluous injury or unnecessary suffering, environmental protection, the principle of distinction, proportionality, precaution.
The interaction between technological development and armed forces is a constant feature of the history of warfare. Technological development can be stimulated by, and dedicated directly to addressing, military requirements. On other occasions, technological development outside the military sphere affects or informs the conduct of warfare and military expectations, as has been illustrated by the application of computing and software innovations that have led to major changes in the military tactics of developed nations.\(^1\) Nanotechnology is widely considered a next-generation transformational technology with profound implications for all aspects of modern society.\(^2\) The introduction of nanotechnology into our civil life and warfare is also expected to influence the application and interpretation of the existing rules of international humanitarian law, raising ‘the question of whether the rules are sufficiently clear in light of the technology’s specific characteristics, as well as with regard to the foreseeable humanitarian impact it may have’.\(^3\)

This article examines the challenges posed to international humanitarian law by the widespread use of nanotechnology-enabled materials and other potential applications of nanotechnology in light of what is feasible at the present stage of scientific research.\(^4\) This assessment can only be preliminary because the full potential of nanotechnology is yet to be revealed. To that end, the article first introduces various applications of nanotechnology relevant to the conduct of modern warfare with a particular focus on armed attacks by conventional weapons.\(^5\) It then examines the impact and influence of nanotechnology for the application of four basic rules of international humanitarian law. It concludes by identifying three

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5. The application of nanotechnology for biological, chemical, or nuclear weapons requires a separate legal analysis by reference to relevant treaty regimes and is therefore excluded from the focus of this article.
areas of concern arising from widespread use of nanotechnology for the application of international humanitarian law.

The relevance of nanotechnology to warfare

Nanotechnology is a rapidly evolving field of science cutting across many disciplines including engineering, quantum physics, optics, chemistry, and biology, and typically involves manipulation of matter on the atomic and molecular level in the size range of 1 nm – 100 nm (1 nm = 10^{-9}m) in one or more external dimensions. Engineered nanomaterials (ENMs) and nanoparticles (ENPs) possess unique characteristics such as flame-retardation, dirt-resistance, increased electrical conductivity, and improved hardness and strength with reduced weight, which have proven to be popular for applications in a wide range of commercially marketed products.

At the same time, however, concerns have been raised about potential toxicity for human health and biological and environmental systems. While no conclusive toxicity profile for engineered nanomaterials and nanoparticles is yet available, there is already compelling scientific evidence of human and environmental toxicity in relation to certain ENMs and ENPs. Examples include the toxicity of multi-walled carbon nanotubes, silver nanomaterials (‘nanosilver’), titanium dioxide nanoparticles, nanoparticle zinc powder, cobalt nanoparticles, and

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7 The Project on Emerging Nanotechnologies at the Woodrow Wilson International Center for Scholars regularly updates an inventory of nanotechnology consumer products, which is available at: http://www.nanotechproject.org/inventories/consumer/ (last visited 30 October 2012).


nickel nanoparticles. Those ENMs and ENPs, when inhaled, typically elicit pulmonary inflammation and cardiovascular problems. Scientific studies have also suggested carcinogenicity, cytotoxicity, and genotoxicity of certain nanomaterials and nanoparticles. These health and environmental hazards are not localized because of the potential long-range transport of nanoparticles through the air and water after their release into the environment.

The relevance of nanotechnology to the military resides particularly in its application to enhance military capabilities including:

- soldier survivability (for example, lighter, stronger, and heat-resistant armour and clothing),
- force protection (for example, enhanced camouflaging, undetectable coating of aircrafts, explosive detectors, bio/chemical sensors);
- force mobility (for example, miniaturization of communication devices, increased energy generation and storage capacity);

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17 CIEL, above note 2, pp. 11–12.
18 The Institute for Soldier Nanotechnologies (ISN) was established as a centre for research collaboration between the US Army and the Massachusetts Institute of Technology to conduct basic and applied research to enhance soldier survivability, see the website at: http://web.mit.edu/ISN/ (last visited 30 October 2012).
22 For a detailed analysis, see Margeret E. Kosal, Nanotechnology for Chemical and Biological Defense, Springer, Dordrecht, 2009, pp. 43–52.
23 J. Wang and P. J. Dortmans, above note 4, p. 28.
penetration capability (for example, nano-energetic explosives, armour-piercing projectiles coated with a nano-material); and
focused force application (for example, ‘nano air vehicles’, self-guiding bullets).

Thus, military applications of nanotechnology extend to both offensive and defensive capabilities. Even purportedly defensive applications, such as enhanced armour and camouflage, provide certain operational and tactical advantages, which could have implications for the interpretation and application of the existing rules of international humanitarian law.

Widespread use of nanotechnologies in commercially marketed products also means that military operations in the modern environment may involve targeting nanotechnology-enabled products or destroying them as collateral damage. For example, building materials may contain nanotechnology-enabled products, such as thermal insulation coating, anti-bacterial paint, and self-cleaning glass. Engineered metal nanomaterials are likely to be widely used for solar power plants and water filtration plants to enhance their capacity and efficiency. Even if ENMs are firmly embedded in larger structures and are therefore difficult to separate from the structural components, strong physical impacts may well result in an accidental release of hazardous ENMs and ENPs when targeted by kinetic means or as a result of fire. Upon release, ENMs and

ENPs may enter into human bodies through inhalation, and also into the environment with the real possibility that nanomaterials may move through food chains and culminate in human exposure. Very little information is currently available on the potential longevity of ENMs and ENPs in the environment, bioaccumulation, and the possibility of detection and removal – particularly in relation to weathered nanoparticles that have undergone agglomeration and transformation. Particularly when ENMs and ENPs are dispersed into the air and water, the risk of long-term, widespread, severe health and environmental damages cannot be easily dismissed.

Health and environmental concerns associated with the use of a particular type of weapon are not unique to nanotechnologies in modern warfare. Concern has been raised, for example, with regard to indirect impacts of metal dust in whatever form it might be released. Illustrative is the Gulf War Syndrome, which is thought to be caused by exposure to toxic chemicals released upon impact by depleted uranium weapons. Scientific evidence also suggests the possibility that the energy-charged, heavy metal tungsten alloy (HMTA) powder released by dense inert metal explosives (DIME) is tumour-generating and capable of genotoxic effects. One significant difference between such toxic chemicals and ENMs or ENPs, however, is that it is not just the military use in weaponry, but more importantly, the widespread civilian use that is likely to cause a large-scale release of toxic substances and hence significantly increase the risk of exposure.

Acknowledging a wide range of beneficial applications of nanotechnology, particularly in addressing national priority issues such as energy security and water...
security, as well as strong interests in the development of nanotechnologies for businesses and industries, it is highly unlikely that national regulatory authorities will move to ban the use of ENMs and ENPs.\textsuperscript{36} Nevertheless, some states have recently started regulating the use of ENMs and ENPs in consumer products based on their ‘use scenario’.\textsuperscript{37} Yet, national regulation will not effectively prevent toxic ENMs and ENPs, released as a result of armed attacks, from posing widespread health and environmental hazards unless the regulation is specifically designed for such an event.\textsuperscript{38}

**Nanotechnology and the principles of international humanitarian law**

Currently there is no international treaty that specifically regulates the use of nanotechnology for military purposes or otherwise. A preventive arms control treaty to regulate or ban the use of nanotechnology for military purposes is unlikely to materialize\textsuperscript{39} because international arms control treaties tend to be reactive to technological developments and are limited in scope, prohibiting or regulating only specific weapons defined by their design, intent, and characteristics.\textsuperscript{40} However, the use of nanotechnology is already restricted to the extent that it is used to develop or enhance weapons that are prohibited by existing arms control treaties, such as biological weapons,\textsuperscript{41} chemical weapons,\textsuperscript{42} non-detectable


\textsuperscript{41} Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction, 10 April 1972, 1015 UNTS 163 (entered into force 26 March 1975).

fragments,\textsuperscript{43} blinding laser weapons,\textsuperscript{44} anti-personnel mines,\textsuperscript{45} explosive remnants of war,\textsuperscript{46} and, most recently, cluster munitions.\textsuperscript{47} Nanotechnology, if used as an enabling technology for weapons development in these areas, would be regulated by the relevant treaty. Nanotechnology, for example, can produce lasers far more powerful than those previously known.\textsuperscript{48} The ability of nanotechnology to design and manipulate molecules with specific properties could lead to bio/chemical agents capable of causing defined hostile results ranging from temporary incapacitation to death, or multilayered biochemical carriers that could easily control the spread of bio/chemical agents.\textsuperscript{49}

General principles of international humanitarian law, conversely, tend to refer to the effects produced by the use of means or methods of warfare.\textsuperscript{50} The general principle that ‘the right of belligerents to adopt means of warfare is not unlimited’ has been codified in international humanitarian law instruments.\textsuperscript{51} This general principle and other rules of international humanitarian law must be read in light of the Martens Clause.\textsuperscript{52} Although ‘principles of humanity’ and ‘dictates of public conscience’ alone may provide no firm legal basis to prohibit the use

\begin{itemize}
\item Protocol (I) on Non-Detectable Fragments 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, 10 October 1980, 1342 UNTS 137 (entered into force 2 December 1983).
\item Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on Their Destruction, 4 December 1997, 2056 UNTS 211 (entered into force 1 March 1999).
\item Convention on Cluster Munitions, 3 December 2008 (entered into force 1 August 2010).
\item Declaration Renouncing the Use, in Time of War, of Explosive Projectiles under 400 Grammes Weight, CTS, Vol. 138, 1868–1869, p. 297, 11 December 1868, reproduced in A. Roberts and R. Guelff, above note 51, pp. 54–55 (hereinafter 1868 St Petersburg Declaration); Additional Protocol I, Art. 1(2), which reads: ‘In cases not covered by this Protocol or by other international agreements, civilians and combatants remain under the protection and authority of the principles of international law derived from established custom, from the principles of humanity and from dictates of public conscience.’
\end{itemize}
of particular weapons, the Martens Clause has become especially important as new technologies increasingly affect the development and sophistication of weapons and delivery systems, something which was not envisaged by the drafters of international humanitarian law instruments.

In light of this, the following sections discuss the legal challenges posed by the development of nanotechnology with respect to four basic rules of international humanitarian law: (1) the obligation to ensure the legality of weapons; (2) distinction; (3) proportionality; and (4) precaution.

The legality of weapons

When assessing the legality of weapons at each stage of their development and acquisition, states are required, under Article 36 of Additional Protocol I, to take into consideration the health-related impact of the use of the weapon. Such assessment, equally valid for nanotechnology, must be based on all the relevant scientific evidence. The principle prohibiting the employment of arms, projectiles, or material ‘of a nature to cause superfluous injury’ (or ‘calculated to cause unnecessary suffering’), as well as the principle prohibiting the ‘methods or means of warfare which are intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment’, is central to the consideration of legality of nanotechnology-enabled or enhanced weapons under international humanitarian law. For the purpose of this weapons review, superfluous injury or unnecessary suffering is examined only in light of the broad and general circumstances in which the weapon is intended for use, as opposed to a particular use of a weapon which is assessed against the rules of distinction, proportionality, and precaution in the operational context of a particular attack.


57 Additional Protocol I, Art. 35(2).

58 Additional Protocol I, Art. 35(3).


The principle prohibiting superfluous injury or unnecessary suffering was first enunciated in the preamble to the 1868 St Petersburg Declaration, but this general principle was a rhetorical expression of the drafters’ inspiration, rather than of their intention to impose legal obligations. It was formally adopted as a binding rule in the subsequent treaties and since then has attained the status of customary international law. This principle applies universally, irrespective of the distinction between civilian and military targets. The prohibition is now incorporated into the 1998 Rome Statute of the International Criminal Court as a war crime. This principle is of central relevance to the use of nanotechnology in the development of weapons, insofar as those weapons could cause unnecessary suffering.

Yet, exactly which use of nanotechnology in weaponry is deemed illegal depends on the interpretation of what constitutes ‘superfluous injury’ and ‘unnecessary suffering’. One may take a subjective approach by looking at the primary purpose for which the new weapon is designed in order to determine whether it causes injury or suffering disproportionate to its military effectiveness. This dominant view suggests that one must balance the degree of injury or suffering inflicted on the one hand, and the degree of military necessity underlying the choice of particular weapon on the other. The other, more objective approach to ‘superfluous injury’ or ‘unnecessary suffering’ under international humanitarian law places greater emphasis on excessive harm inflicted on the victim in relation to the damage necessary to place a combatant hors de combat for the duration of combat.

61 It reads that ‘the employment of arms which uselessly aggravate the sufferings of disabled men, or render their death inevitable … would, therefore, be contrary to the laws of humanity’.
62 F. Kalshoven, above note 40, p. 511.
63 Hague Convention (II) Respecting the Laws and Customs of War on Land, CTS, Vol. 187, 1899, p. 227, 29 July 1899 (entered into force 4 September 1900), Art. 23(e); 1907 Hague Regulations, Art. 23(e). Although the authentic French text remained the same (maux superflus), the identical phrase in the two instruments was translated differently. The English translation of the treaty texts is provided in James Brown Scott, The Hague Conventions and Declarations of 1899 and 1907, Oxford University Press, New York, 1915, p. 116. Article 35(2) of Additional Protocol I places those two expressions side by side.
Depending on which approach is taken, the legality of a military application of nanotechnology may well be considered differently. This is particularly so when the application of nanotechnology is designed to enhance penetration capabilities of a weapon, such as thermobaric explosives, to destroy targets inside hardened and deeply buried structures or buildings, yet potentially involving hazardous health and environmental impacts. For example, the deployment of nano-energetic thermobaric explosives could well be justified on the grounds that targeting terrorists or insurgents inside hardened compounds outweighs considerations of severe suffering from the primary blast or thermal damage for combatants or civilians taking a direct part in hostilities.

There is a subtle difference under this international humanitarian law principle between ‘injury’ and ‘suffering’. The former indicates immediate, physical damage, whereas the latter may entail the incidence of permanent damage or disfigurement. This distinction, and emphasis on permanent damage or disfigurement, is of increased significance given that, as is the case with ENMs and ENPs, technological advancement is making it more difficult to scientifically appreciate the full range of damaging effects of a new weapon on the human body by looking only at the weapon’s construction. In fact, the idea to extend the meaning of suffering even to harmful effects that ensue after the end of hostilities reportedly influenced the treaty negotiations about blinding laser weapons, particularly the long-term impact of blind veterans on society. An expanded reading of suffering in the application of this principle is one way of casting light on social costs associated with the health and environmental hazards produced by the release of toxic ENMs and ENPs during warfare, which are imposed upon peace-building efforts in the aftermath of warfare. Yet, scientific uncertainty surrounding the health and environmental effects of ENMs and ENPs, particularly in relation to the causal link between the weapon and the hazards, makes it a formidable task to prove the suffering. This is due to the difficulties of adequately accounting for combined toxic effects of, and interactions between, different substances.

Insofar as the toxic effects of ENMs and ENPs could extend to the natural environment, including micro-organisms in the soil and water and follow-on effects


on the food chain, the legality of nanotechnology-enabled or enhanced weapons must also be considered in light of Article 35(3) of Additional Protocol I. This provision prohibits the use of ‘methods or means of warfare which are intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment’.75 This threshold is understood to constitute cumulative requirements and hence impose significant obstacles to ruling any particular attack illegal.76 Nonetheless, it is debatable whether toxic ENMs and ENPs, released upon impact of nanotechnology-enabled or enhanced weapons (and also arguably as a result of deliberately targeting nanotechnology-enabled or enhanced objects by conventional kinetic means), have the potential to satisfy this threshold. This is because of the unique characteristics of ENMs and ENPs such as high emission rates,77 the potential long-range transport through agglomeration or attachment to pre-existing background aerosol particles,78 and low solubility.79 Unlike toxic chemical agents, ENMs and ENPs do not dissolve or biodegrade in the environment. Also, unlike biological agents, ENMs and ENPs may travel a long distance without requiring living organisms as carriers for transmission.

Unlike the prohibition on superfluous injury or unnecessary suffering, this environmental protection clause is understood as imposing a ‘should have known’ standard for finding breach without leaving scope for balancing against military necessity or proportionality.80 It is not clear what level or amount of knowledge or information is required regarding the potential consequences of using nanotechnology-enabled or enhanced weapons, given the currently inconclusive scientific evidence regarding widespread, long-term, and severe environmental hazards posed by the dispersion of ENMs and ENPs. If the health or environmental

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75 The ICRC Commentary considers that the term ‘natural environment’ in the Protocol refers to the ‘system of inextricable interrelations between living organisms and their inanimate environment’: ICRC Commentary, above note 68, para.1451.
concerns fail to reach this threshold, then they would have to be considered in light of whether the prohibition on superfluous injury or unnecessary suffering extends to accommodate those concerns as ‘suffering’.

Distinction

The cardinal point in the principle of distinction is that combatants are clearly distinguishable from civilians, who are not to be directly targeted.81 This principle is enunciated in Article 48 of Additional Protocol I, which reads: ‘[t]he Parties to the conflict shall at all times distinguish between the civilian population and combatants … and accordingly shall direct their operations only against military objectives.’82 This principle imposes two inextricably connected obligations: it requires states to direct their military attacks only against combatants, on the one hand; and, in order to enable states to comply with the first obligation, it requires them to distinguish combatants from civilians by means of, inter alia, ‘a characteristic piece of clothing which is visible’.83

Stealth technology has already been introduced for military aircraft to reduce the visibility and the probability of detection by radar, infrared, or other probe beams.84 However, nanofabrication technology has the potential to enhance this stealth technology further by enabling optical camouflage (also often called adaptive camouflage).85 Using optical camouflage in all of three light spectrums – visible light, night-vision spectrum, and thermal/infrared spectrum – to cloak soldiers and their equipment will enable complete invisibility, undetectable by any traditional means of warfare until a new detection technology is developed.86 Camoufllaging is a typical example of traditional military tactics of deception permitted as ruses of warfare.87 It is not prohibited insofar as no rule of international humanitarian law is infringed and it cannot be considered a perfidious act insofar as it does not invite the confidence of the enemy with respect to protection under international humanitarian law.88

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81 The principle of distinction has been recognized as customary international law. See, e.g., Legality of Nuclear Weapons Advisory Opinion, above note 53, p. 257, para. 78; J.-M. Henckaerts and L. Doswald-Beck, above note 64, Vol. 1, Rule 1.
82 Additional Protocol I, Art. 48. See also, 1907 Hague Regulations, Art. 1(2) (requiring combatants ‘to have a fixed distinctive emblem recognizable at a distance’ (emphasis added)); Geneva Convention Relative to the Treatment of Prisoners of War of August 12, 1949, 12 August 1949, 75 UNTS 135 (entered into force 21 October 1950), Art. 4(A)(2)(b) (‘having a fixed distinctive sign recognizable at a distance’ (emphasis added)).
83 ICRC Commentary, above note 68, p. 528, para. 1693.
85 See A. Di Falco et al., above note 19.
86 See H. Shi et al., above note 20, p. 211103-1 (suggesting that the low refractive index of carbon nanotubes can absorb light and cloak an object against a black background).
88 Additional Protocol I, Art. 37(1) and (2).
Yet, in situations where cloaked combatants launch attacks from within a civilian-populated area, the only way the adverse party can counter-attack is to fire in the direction the attacks came from without being able to identify or distinguish combatants from civilians. The adverse party is thus prevented from complying with the principle of distinction. Similar difficulties have arisen in situations where combatants are firing from civilian buildings; however, enhanced optical camouflaging effectively deprives the adverse party of any chance to detect lawful military targets. This may well raise a significant issue challenging the application of the principle of distinction. Thus cloaking devices must be used with necessary precautions against endangering civilians.89

The application of nanotechnology to facilities for complete or partial military use, on the other hand, does not challenge the application of the principle of distinction. Attacks must be directed against legitimate military objectives, which are defined by Article 52(2) of Additional Protocol I, as objects ‘which by their nature, location, purpose, or use make an effective contribution to military action and whose total or partial destruction, capture, or neutralization, in the circumstances ruling at the time, offer a definite military advantage’. Therefore, any facility, installation, or building, no matter how or whether ENMs and ENPs are used, is not immune from becoming a legitimate military target.

Special protection is accorded to dams, dykes, and nuclear electricity-generating stations under Article 56 of Additional Protocol I because of concern about the release of dangerous forces and consequent severe damage to the civilian population as a result of an attack against those works and installations.90 Yet, alternative electricity-generating stations, such as nanotechnology-enhanced solar power plants,91 do not fall under this category of specially protected objects. Even if targeting nanotechnology-enhanced solar power plants may result in the release of toxic ENMs and ENPs into the environment and human bodies, the environmental and health risks do not make those plants immune from direct military attacks. Rather, as will be discussed below, those effects are more likely to be relevant to the principles of proportionality and precaution.

Thus, no electricity-generating station, whether nanotechnology enhanced or not, is currently protected from direct attacks under international humanitarian law. It is arguable that, in the future, attacks against nanotechnology-enhanced power plants could result in the release of dangerous forces, prompting a call to amend Article 56 of Additional Protocol I to expand the scope of its legal protection. Alternatively, society may move to more decentralized electricity generation relying on solar panels in each household. In that case, the mere possibility that electric

89 Additional Protocol I, Art. 57.
90 Although it refers generally to ‘works and installations containing dangerous forces’, the term ‘namely’ and the intention of the parties during the treaty negotiations make it clear that protected objects are only those listed in the provision. See ICRC Commentary, above note 68, pp. 668–669, paras. 2146–2150; M. Bothe, K. J. Partsch and W. A. Solf, above note 70, p. 354.
91 As noted above, engineered metal nanomaterials are widely seen as having a great potential to enhance the capacity and efficiency of solar power plants. See above note 30 and accompanying text.
power generated from each household is used for military purposes would not necessarily make civilian houses legitimate military objectives.92

Proportionality

The principle of proportionality is widely recognized as a rule of customary international law regulating the conduct of warfare both in international and non-international armed conflicts.93 Although the term ‘proportionality’ does not appear in the text of Additional Protocol I,94 the gist of the principle is reflected in Article 51(5)(b) as an example of indiscriminate attack and also in Article 57(2)(a)(iii) as one of the precautions to be taken, prohibiting ‘an attack which may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage anticipated’. The inherent subjectivity in assessing excessiveness while balancing two different values – anticipated military advantage and expected incidental losses – has been a subject of controversy and even criticism of the practicality of this principle.95

Relevant to the implications of nanotechnology is the question as to what extent the ‘effect’ of attacks must be taken into account in the proportionality calculus, given that the potential health and environmental effects of ENMs and ENPs are the primary concerns about the use of nanotechnology among regulators around the world.96 The larger the radius of incidental civilian losses is drawn, the more difficult it may become to justify the damage on proportionality grounds. Indirect costs and long-term effects (sometimes called reverberating effects) of a military attack tend to be ignored in the proportionality calculus, as the indirect effects are less visible than direct damage and more difficult to ascertain.97 However, to the extent that the principle of proportionality is based on the idea of humanity and is influenced by the development of human rights norms,98 a greater awareness of the indirect and long-term impacts of military attacks may well challenge the validity of traditional practice. Thus, Henry Shu and David Wippman, for example, consider that the loss of a civilian function as a result of destroying a dual-use facility (such as electricity-generating plant) should not be discounted from

96 See literature cited above note 8.
the proportionality calculus merely because the object is a military objective.\textsuperscript{99} More relevantly, considering the implications of recent technological improvements, Michael Schmitt suggests that humanitarian attention may well centre on reverberating effects or derivative consequences, ‘now that the means exist to limit dramatically direct collateral damage and incidental injury that we are being sensitized to reverberation’.\textsuperscript{100}

Environmental concerns are already acknowledged in a general principle of proportionality. The International Court of Justice (ICJ) observed in its advisory opinion on \textit{Legality of the Threat or Use of Nuclear Weapons} that ‘[s]tates must take environmental considerations into account when assessing what is necessary and proportionate in the pursuit of legitimate military objectives’.\textsuperscript{101} Yet, the extent to which states are required to take environmental considerations into account is far from clear. If the principle of proportionality is read in conjunction with Article 55(1) of Additional Protocol I, relevant considerations are narrowly confined to ‘widespread, long-term and severe damage to the natural environment’. Unlike the prohibition under Article 35(3) of Additional Protocol I, environmental considerations referred to in Article 55(1) impose only a duty of care and are focused on the health and survival of the population.\textsuperscript{102} This suggests that even if nanotechnology is not involved in the methods or means of warfare employed, commanders are under a duty of care not to cause widespread, long-term, and severe environmental damage that threatens the health or survival of the population when targeting nanotechnology-enabled or enhanced facilities, whether they are legitimate military objectives or not.

Here, the consideration of environmental effects in the context of Article 55(1) of Additional Protocol I is subject to two qualifications. First, commanders are required to take into account widespread, long-term, and severe environmental damage that may be expected to jeopardize the survival of the population or seriously prejudice health by causing, for example, congenital defects, degenerations, or deformities.\textsuperscript{103} Therefore, one needs to speculate: (i) whether the attack is likely to involve destruction of nanotechnology-enabled or enhanced facilities; (ii) whether ENMs and ENPs released upon impact might cause widespread, long-term, and severe environmental damage; and (iii) how human bodies and genes are affected by contact with those substances. Yet, the process of transformation, agglomeration, and fusion with larger substances cause tremendous


\textsuperscript{102} The provision, in full text, reads: ‘\textit{Care shall be taken in warfare to protect the natural environment against widespread, long-term and severe damage. This protection includes a prohibition of the use of methods or means of warfare which are intended or may be expected to cause such damage to the natural environment and thereby to prejudice the health or survival of the population}’ (emphasis added). For the difference between Article 35(3) and Article 55(1), see, Michael N. Schmitt, ‘Humanitarian law and the environment’, in \textit{Denver Journal of International Law and Policy}, Vol. 28, 2000, pp. 275–277.

\textsuperscript{103} ICRC Commentary, above note 68, pp. 663–664, para. 2135.
scientific difficulties for the precise understanding of the nature and extent of health effects. In future conflicts, commanders will have to face ‘the fog of science’ in battlefields and exercise the duty of care based on the uncertain probability of risk.

Second, the duty of care leaves some latitude for judgement. It is in this context that the principle of proportionality arguably finds its application in relation to environmental collateral damage. This idea is given a clear expression in Article 8(2)(b)(iv) of the 1998 Rome Statute, which provides in its definition of war crimes:

> Intentionally launching an attack in the knowledge that such attack will cause incidental loss of life or injury to civilians or damage to civilian objects or widespread, long-term and severe damage to the natural environment which would be clearly excessive in relation to the concrete and direct overall military advantage anticipated.

Thus, as an element of war crime, environmental damage, to a limited extent, has been incorporated into the proportionality assessment. Yet again, the scientific uncertainty with regard to the full extent and nature of the environmental and health damage caused by the release of and contact with toxic ENMs and ENPs raises challenging questions as to whether the mere availability of scientific evidence is sufficient to constitute ‘knowledge’ and how the potentially hazardous environmental and health effects are considered ‘excessive’. The same questions apply to the proportionality requirement under international humanitarian law, even though the element of knowledge is more loosely expressed.

Due to these two qualifications, therefore, the application of Article 55(1) of Additional Protocol I is of little practical use when regulating the conduct of warfare to restrict or prevent widespread, long-term and severe environmental damage that may be caused by the dispersion of toxic ENMs and ENPs as a result of military attacks. Conversely, Article 51(5)(b) of Additional Protocol I does not require the expected environmental damage to be widespread, long-term, or severe, and therefore arguably allows for a greater scope of incidental loss to accommodate the consideration of potential environmental and health effects of dispersed ENMs and ENPs, though this scope depends on how widely the incidental loss can be interpreted.


105 ICRC Commentary, above note 68, p. 663, para. 2133.


108 Additional Protocol I, Arts 51(5)(b), 55(1), and 57(2)(a)(iii) (using the expression ‘may be expected’).
Precaution

Two different obligations of precaution are stipulated in Articles 57 and 58 of Additional Protocol I: precaution in attack and precaution in defence, respectively.\(^{109}\) It is widely accepted that the obligation to take precautions in planning or deciding upon an attack is a rule of customary international law.\(^{110}\) To the extent that the wording of Article 57 incorporates the principle of proportionality, the same legal issue will arise as discussed above in relation to the degree to which health and environmental harm caused by the release of toxic ENMs and ENPs upon impact in an armed attack are considered civilian losses. The obligation of precaution raises an additional issue as to what extent indirect or reverberating effects should be foreseeable – in other words, what level or amount of knowledge is required as the basis for taking precautions.

Interestingly, the ICRC’s Customary International Humanitarian Law Study understands that the principle of precaution is to be observed even if there is scientific uncertainty as to the effects on the environment of certain military operations.\(^{111}\) It is debatable to what extent that reading of the ‘precautionary principle’, which has developed in the field of international environmental law, has been accepted as an interpretation of the obligation to take precautions under international humanitarian law.\(^{112}\) However, an application of the precautionary principle in the modern world of nanotechnology would pose significant challenges to military operations, insofar as it would require taking all feasible precautions to minimize the release of toxic ENMs and ENPs as a result of armed attacks, even in the absence of scientific certainty as to the actual toxic effects. It may well be unrealistic to expect that a decision be made to halt an attack on the grounds that the potential health and environmental damage is considered excessive in relation to the concrete and direct military advantage anticipated.

This issue also needs to be addressed in the context of precaution in defence. Article 58 of Additional Protocol I requires state parties to take feasible precautions to, among others things, ‘protect civilians and civilian objects against the dangers resulting from military operations’ (emphasis added). While this obligation is arguably considered a rule of customary international law,\(^{113}\) the reality is that national regulatory authorities in modern society rarely pay heed to the possibility of future warfare and its effects for civilian life.\(^{114}\) The seriousness of this

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109 For a detailed analysis, see Jean-François Quéguiner, ‘Precautions under the law governing the conduct of hostilities’, in International Review of the Red Cross, Vol. 88, No. 864, pp. 793–821.
111 Ibid., Rule 44.
oversight was illustrated by the increased number of cancer-related deaths in
the aftermath of the 9/11 terrorist attacks in New York due to the exposure to toxic
dust released from the collapsed buildings.\textsuperscript{115} With the impending threat of
health and environmental hazards potentially resulting from the release of toxic
ENMs and ENPs during warfare, a greater recognition of the obligation to take
precautions to protect civilians from the effects of armed attacks arguably has
the potential to encourage and facilitate more comprehensive nanotechnology
regulation encompassing the prevention and control of exposure to toxic ENMs
and ENPs.

Conclusion

Nanotechnology may well be seen as of little concern for the implementation of
international humanitarian law in modern warfare, particularly if direct civilian
casualties are reduced by the introduction of more sophisticated, precise, and
efficient weapons and delivery systems enabled or enhanced by nanotechnology.
One need only recall the traditionally held view that the legitimate objective
in warfare is to weaken enemy forces by disabling the greatest possible number
of combatants.\textsuperscript{116} However, the focus of modern warfare has been shifting
more towards precision-focused, effects-based military operations, which places an
emphasis on achieving certain results rather than the absolute destruction of enemy
forces.\textsuperscript{117} This shift of military doctrine arguably underlines a greater need to
reconsider how and to what extent the potential hazardous effects of ENMs and
ENPs on health and the environment should or should not be taken into account
when applying basic rules of international humanitarian law.

By examining this question, this article has identified three areas of concern
for the application of international humanitarian law that arise from widespread
use of nanotechnology. First, scientific uncertainty surrounding the health and
environmental impacts of ENMs and ENPs raises an issue concerning the level
or amount of knowledge required when considering the legality of a weapon,
assessing the excessiveness of an attack, and taking precautions during targeting
decision-making. Second, there is no clear guidance as to how widely health and
environmental effects resulting from armed attacks must be taken into account,
except when the effects are intended, or may be expected, to be widespread, long-
term, and severe. This is because of the unsettled debate over the extent to which
indirect, long-term impacts should be taken into account when considering what

\textsuperscript{115} See, World Trade Center Health Program: Addition of Certain Types of Cancer to the List of WTC-
\textsuperscript{116} See, Preamble to the 1868 St Petersburg Declaration, above note 52.
\textsuperscript{117} See, e.g., Tomislav Z. Ruby, ‘Effects-based operations: more important than ever’, in \textit{Parameters}, Vol. 38,
2006, p. 43; Elinor C. Sloan, \textit{The Revolution in Military Affairs: Implication for Canada and NATO},
McGill-Queen’s University Press, 2002, p. 15; David A. Deptula, \textit{Effects-Based Operations: Change in the
constitutes superfluous injury or unnecessary suffering and also when assessing the excessiveness of an attack. Third, the principle of distinction and the obligation to take precautions will become more difficult to sustain unless the significance of more comprehensive nanotechnology regulation envisaging wartime situations is recognized by national regulatory authorities.