Nanotechnology and challenges to international humanitarian law: a preliminary legal assessment

Hitoshi Nasu

International Review of the Red Cross / Volume 94 / Issue 886 / June 2012, pp 653 - 672
DOI: 10.1017/S181638311200077X, Published online: 15 April 2013

Volume 94 Number 886 Summer 2012

INTERNATIONAL REVIEW of the Red Cross

Nanotechnology and challenges to international humanitarian law: a preliminary legal assessment

Hitoshi Nasu*

Hitoshi Nasu is Senior Lecturer in law at the Australian National University, Canberra, Australia.

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 author thanks Associate Professor Robert McLaughlin, Professor Ken Watkin, CAPT Andy Norris, CAPT (Ret.) Dennis Mandsager, Lt Col. George Cadwalader, MAJ Matt Hover, Ms Sasha Radin, Professor Tom Faunce, and anonymous reviewers for their invaluable comments on an earlier draft, and Rosanna Bartlett, David Rowe, and Pauline Wilson for their research assistance. The author also gratefully acknowledges the support of the Australian Research Council under its Discovery Grant funding scheme (Project ID110102637).

doi:10.1017/S181638311200077X

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

1 See generally, Peter Dombrowski and Eugene Gholz, *Buying Military Transformation: Technological Innovation and the Defense Industry*, Columbia University Press, New York, 2006; Henry C. Bartlett *et al.*, 'Force planning, military revolutions and the tyranny of technology', in *Strategic Review*, Vol. 24, No. 4, Fall 1996, pp. 28–40.

2 See e.g., the Center for International Environmental Law (CIEL), *Addressing Nanomaterials as an Issue of Global Concern*, May 2009, p. 1, available at: http://www.ciel.org/Publications/CIEL_NanoStudy_May09.pdf (last visited 30 October 2012).

3 International Committee of the Red Cross, *International Humanitarian Law and the Challenges of Contemporary Armed Conflicts*, Report on the 31st International Conference of the Red Cross and Red Crescent, Geneva, 28 November–1 December 2011, p. 36, available at: http://www.icrc.org/eng/resources/documents/report/31-international-conference-ihl-challenges-report-2011-10-31.htm (last visited 30 October 2012). For an earlier study on the impact of technology in general on international humanitarian law, see especially, Michael N. Schmitt, 'War, technology and the law of armed conflict', in Anthony M. Helm (ed.), *The Law of War in the 21st Century: Weaponry and the Use of Force*, US Naval War College International Law Studies, Vol. 82, Naval War College, Newport, 2006, p. 137.

4 Thus, this article does not concern futuristic, speculative applications of nanotechnology, such as universal molecular assemblers and autonomous nano-robots, though some of the findings in this article may well be applicable to them. For a comprehensive account of scientifically possible applications of nanotechnology, see, e.g., Jürgen Altmann, *Military Nanotechnology*, Routledge, London, 2006; Jun Wang and Peter J. Dortmans, 'A review of selected nanotechnology topics and their potential military applications', Defence Science and Technology Organisation, Australian Government Department of Defence, 2004, pp. 22–30, available at: http://www.dsto.defence.gov.au/publications/2610/DSTO-TN-0537.pdf (last visited 30 October 2012).

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.

INTERNATIONAL REVIEW of the Red Cross

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.[6] 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.[7]

At the same time, however, concerns have been raised about potential toxicity for human health and biological and environmental systems.[8] 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,[9] silver nanomaterials ('nanosilver'),[10] titanium dioxide nanoparticles,[11] nanoparticle zinc powder,[12] cobalt nanoparticles,[13] and

6 For different definitions of nanotechnology, see, e.g., European Commission, Commission Recommendation on the definition of nanomaterial, available at: http://ec.europa.eu/environment/chemicals/nanotech/pdf/commission_recommendation.pdf (last visited 30 October 2012); US Environmental Protection Agency (EPA), *Nanotechnology White Paper*, Office of the Science Advisor, EPA 100/B-07/001, February 2007, p. 5, available at: http://www.epa.gov/osa/pdfs/nanotech/epa-nanotechnology-whitepaper-0207.pdf (last visited 30 October 2012).

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).

8 See, e.g., US EPA, above note 6, pp. 29–62; UK Department for Environment, Food and Rural Affairs, 'Characterising the potential risks posed by engineered nanoparticles: a second UK government research report', 2007, available at: http://www.defra.gov.uk (last visited 30 October 2012); UK Royal Society & Royal Academy of Engineering, *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*, 2004, available at: http://www.nanotec.org.uk/finalReport.htm (last visited 30 October 2012).

9 See, e.g., Massimo Bottini *et al.*, 'Multi-walled carbon nanotubes induce T lymphocyte apoptosis', in *Toxicology Letters*, Vol. 160, 2006, pp. 121–126.

10 See, e.g., Maqusood Ahamed, Mohamad S. Alsalhi and M. K. J. Siddiqui, 'Silver nanoparticle applications and human health', in *Clinica Chimica Acta*, Vol. 411, 2010, pp. 1841–1848; Susan W. P. Wijnhoven *et al.*, 'Nano-silver – a review of available data and knowledge gaps in human and environmental risk assessment', in *Nanotoxicology*, Vol. 3, No. 2, 2009, pp. 109–138.

11 See, e.g., Benedicte Trouiller *et al.*, 'Titanium dioxide nanoparticles induce DNA damage and genetic instability in vivo in mice', in *Cancer Research*, Vol. 69, No. 22, 2009, pp. 8784–8789.

12 See, e.g., Bing Wang *et al.*, 'Acute toxicity of nano- and micro-scale zinc powder in healthy adult mice', in *Toxicology Letters*, Vol. 161, No. 2, 2006, pp. 115–123.

13 See, e.g., Limor Horev-Azaria *et al.*, 'Predictive toxicology of cobalt nanoparticles and ions: comparative *in vitro* study of different cellular models using methods of knowledge discovery from data', in *Toxicological Sciences*, Vol. 122, No. 2, 2011, pp. 489–501.

nickel nanoparticles.[14] Those ENMs and ENPs, when inhaled, typically elicit pulmonary inflammation and cardiovascular problems.[15] Scientific studies have also suggested carcinogenicity, cytotoxicity, and genotoxicity of certain nanomaterials and nanoparticles.[16] 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.[17]

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);[18]
- force protection (for example, enhanced camouflaging,[19] undetectable coating of aircrafts,[20] explosive detectors,[21] bio/chemical sensors[22]);
- force mobility (for example, miniaturization of communication devices,[23] increased energy generation and storage capacity[24]);

14 See, e.g., Jodie R. Pietruska *et al.*, 'Bioavailability, intracellular mobilization of nickel, and HIF-1α activation in human lung epithelial cells exposed to metallic nickel and nickel oxide nanoparticles', in *Toxicological Sciences*, Vol. 124, No. 1, 2011, pp. 138–148.

15 See, e.g., Weiyue Feng *et al.*, 'Nanotoxicity of metal oxide nanoparticles *in vivo*', in Saura C. Sahu and Daniel A. Casciano (eds), *Nanotoxicology: From In Vivo and In Vitro Models to Health Risks*, John Wiley & Sons, West Sussex, 2009, pp. 247–269; Ken Donaldson *et al.*, 'Pulmonary and cardiovascular effects of nanoparticles', in Nancy A. Monteiro-Riviere and C. Lang Tran (eds), *Nanotoxicology: Characterization, Dosing and Health Effects*, Informa Healthcare, New York, 2007, pp. 267–298; Günter Oberdörster *et al.*, 'Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles', in *Environmental Health Perspectives*, Vol. 113, No. 7, 2005, pp. 829–833.

16 See generally, Shareen H. Doak *et al.*, 'Genotoxicity and cancer', in Bengt Fadeel *et al.*, (eds), *Adverse Effects of Engineered Nanomaterials: Exposure, Toxicology, and Impact on Human Health*, Elsevier, London, 2012, pp. 243–261; Laetitia Gonzalez, Dominique Lison and Micheline Kirsch-Volders, 'Genotoxicity of engineered nanomaterials: a critical review', in *Nanotoxicology*, Vol. 2, No. 4, 2008, pp. 252–273.

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).

19 See, e.g., Andrea Di Falco, Martin Ploschner and Thomas F. Krauss, 'Flexible metamaterials at visible wavelengths', in *New Journal of Physics*, Vol. 12, 2010, p. 113006.

20 See, e.g., Haofei Shi *et al.*, 'Low density carbon nanotube forest as an index-matched and near perfect absorption coating', in *Applied Physics Letter*, Vol. 99, 2011, p. 211103.

21 See, e.g., I. A. Levitsky, 'Highly sensitive and selective explosive detector based on nanoporous silicon photonic crystal infiltrated with emissive organics', in *IEEE Nanotechnology Magazine*, September 2010, p. 24.

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.

24 The US Department of Defense identified electrochemical power source applications of nanotechnology as one of the primary goals of its nanotechnology research and development programme. See US Department of Defense, 'Defense nanotechnology research and development program', 2007, available at: http://www.fas.org/irp/agency/dod/nano2007.pdf (last visited 30 October 2012).

- penetration capability (for example, nano-energetic explosives,[25] armour-piercing projectiles coated with a nano-material[26]); and
- focused force application (for example, 'nano air vehicles',[27] self-guiding bullets[28]).

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.[29] Engineered metal nanomaterials are likely to be widely used for solar power plants and water filtration plants to enhance their capacity and efficiency.[30] 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.[31] Upon release, ENMs and

25 Jefferson D. Raynolds, 'Collateral damage on the 21st century battlefield: enemy exploitation of the law of armed conflict, and the struggle for a moral high ground', in *Air Force Law Review*, Vol. 56, 2005, p. 99 (nano-energetics provide more effective control of blast, relying on nano-structured explosives and fuel additives, as well as catalytics and photovoltaics); Andrzej W. Miziolek, 'Nanoenergetics: an emerging technology area of national importance', in *Advanced Materials and Processes Technology Information Analysis Center (AMPTIAC) Newsletter*, Vol. 6, No. 1, 2002, p. 43.

26 An advanced armour-piercing projectile involving the potential use of NanoSteel™ is patented in the US: Daniel James Branagan, 'Layered metallic material formed from iron based glass alloys', The Nanosteel Company, Inc., US Patent 7482065, 21 April 2009, available at: http://www.freepatentsonline.com/7482065.html (last visited 30 October 2012).

27 The 'nano air vehicles' are extremely small, ultra-lightweight airborne vehicles capable of performing a military mission, developed by the US Defense Advance Research Projects Agency (DARPA). See, William A. Davis, 'Nano air vehicles: a technology forecast', Blue Horizons Paper, Center for Strategy and Technology, US Air War College, 2007, available at: http://www.au.af.mil/au/awc/awcgate/cst/bh_davis.pdf (last visited 30 October 2012).

28 Duncan Blake and Joseph S. Imburgia, '"Bloodless weapons"? The need to conduct legal reviews of certain capabilities and the implications of defining them as "weapons"', in *Air Force Law Review*, Vol. 66, 2010, p. 180.

29 See, e.g., Sabine Greßler and André Gazsó, 'Nano in the construction industry', in *NanoTrust Dossiers*, No. 32, 2012, available at: http://epub.oeaw.ac.at/ita/nanotrust-dossiers/dossier032en.pdf (last visited 1 November 2012).

30 See, e.g., Tao Chen *et al.*, 'Flexible, light-weight, ultrastrong, and semiconductive carbon nanotube fibers for a highly efficient solar cell', in *Angewandte Chemie International Edition*, Vol. 50, 2011, pp. 1815–1819; OECD, 'Fostering nanotechnology to address global challenges: water', 2011, available at: http://www.oecd.org/dataoecd/22/58/47601818.pdf (last visited 1 November 2012).

31 Grazyna Bystrzejewska-Piotrowska, Jerzy Golimowski and Pawel L. Urban, 'Nanoparticles: their potential toxicity, waste and environmental management', in *Waste Management*, Vol. 29, 2009, p. 2592. In fact, Canadian fire services consider released ENMs and ENPs to be serious health hazards. See, Ed Ballam, 'Nanotechnology spells danger for firefighters', in *Firehouse.com News*, 24 April 2012, available at: http://www.firehouse.com/news/10705138/nanotechnology-spells-danger-for-firefighters (last visited 30 October 2012).

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.[32] 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.[33] 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.[34] 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.[35] 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

32 R. D. Handy and B. J. Shaw, 'Toxic effects of nanoparticles and nanomaterials: implications for public health, risk assessment and the public perception of nanotechnology', in *Health, Risk & Society*, Vol. 9, No. 2, 2007, pp. 125–144.

33 Stephen J. Klaine *et al.*, 'Paradigms to assess the environmental impact of manufactured nanomaterials', in *Environmental Toxicology and Chemistry*, Vol. 31, No. 1, 2012, pp. 3–14; Satinder K. Brar, Mausam Verma, R. D. Tyagi and R. Y. Surampalli, 'Engineered nanoparticles in wastewater and wastewater sludge – evidence and impacts', in *Waste Management*, Vol. 30, 2010, pp. 504–520; CIEL, above note 2; US EPA, above note 6, pp. 36–41.

34 Initially, no causal link was established. However, scientific evidence proving the hazardous effects of toxic chemicals released upon impact of deplete uranium weapons has continued to mount. For details, see, e.g., Dan Fahey, 'Environmental and health consequences of the use of depleted uranium weapons', in Avril McDonald, Jann K. Kleffner and Brigit Toebes (eds), *Depleted Uranium Weapons and International Law: A Precautionary Approach*, T. M. C. Asser Press, The Hague, 2008, pp. 29–72; Melissa A. McDiarmid *et al.*, 'Health effects of depleted uranium on exposed Gulf War veterans: a 10-year follow-up', in *Journal of Toxicology and Environmental Health*, Vol. 67, No. 4, 2004, pp. 277–296; The Royal Society Working Group on the Health Hazards of Depleted Uranium Munitions, 'The health effect of depleted uranium munitions: a summary', in *Journal of Radiological Protection*, Vol. 22, 2002, pp. 132–134.

35 See, e.g., Erik Q. Roedel *et al.*, 'Pulmonary toxicity after exposure to military-relevant heavy metal tungsten alloy particles', in *Toxicology and Applied Pharmacology*, Vol. 259, 2012, pp. 74–86; John F. Kalinich *et al.*, 'Embedded weapons-grade tungsten alloy shrapnel rapidly induces metastatic high-grade rhabdomyosarcomas in F344 rats', in *Environmental Health Perspective*, Vol. 113, 2005, pp. 729–734; Alexandra C. Miller *et al.*, 'Neoplastic transformation of human osteoblast cells to the tumorigenic phenotype by heavy metal tungsten alloy particles: induction of genotoxic effects', in *Carcinogenesis*, Vol. 22, 2001, pp. 115–125.

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.[36] Nevertheless, some states have recently started regulating the use of ENMs and ENPs in consumer products based on their 'use scenario'.[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.[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[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.[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,[41] chemical weapons,[42] non-detectable

36 For a detailed analysis of the failed attempt to ban the use of multi-walled carbon nanotubes and silver nanomaterials in the European Union, see, Hitoshi Nasu and Tom Faunce, 'The proposed ban on certain nanomaterials for electrical and electronic equipment in Europe and its global security implications: a search for an alternative regulatory approach', in *European Journal of Law and Technology*, Vol. 2, No. 3, 2011, available at: http://ejlt.org//article/view/79 (last visited 30 October 2012).

37 See, e.g., National Industrial Chemicals Notification and Assessment Scheme (NICNAS), 'Guidance on new chemical requirements for notification of industrial nanomaterials', 2010, available at: http://www.nicnas.gov.au/Current_Issues/Nanotechnology/Guidance%20on%20New%20Chemical%20Requirements%20for%20Notification%20of%20Industrial%20Nanomaterials.pdf (last visited 30 October 2012).

38 Hitoshi Nasu and Tom Faunce, 'Nano-safety or nano-security? Reassessing Europe's nanotechnology regulation in the context of international security law', in *European Journal of Risk Regulation*, Vol. 3, 2012, pp. 416–421.

39 See Jim Whitman, 'The arms control challenges of nanotechnology', in *Contemporary Security Policy*, Vol. 32, No. 1, 2011, pp. 99–115. Cf. J. Altmann, above note 4, pp. 154–176; Sean Howard, 'Nanotechnology and mass destruction: the need for an inner space treaty', in *Disarmament Diplomacy*, Vol. 65, 2002, available at: http://www.acronym.org.uk/dd/dd65/65op1.htm (last visited 30 October 2012).

40 Frits Kalshoven, 'The Conventional Weapons Convention: underlying legal principles', in *International Review of the Red Cross*, Vol. 30, No. 279, 1990, p. 518; Timothy L. H. McCormack, 'A non-liquet on nuclear weapons – the ICJ avoids the application of general principles of international humanitarian law', in *International Review of the Red Cross*, No. 316, 1997, p. 90.

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).

42 Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction, 13 January 1993, 1974 UNTS 45 (entered into force 29 April 1997).

fragments,[43] blinding laser weapons,[44] anti-personnel mines,[45] explosive remnants of war,[46] and, most recently, cluster munitions.[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.[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.[49]

General principles of international humanitarian law, conversely, tend to refer to the effects produced by the use of means or methods of warfare.[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.[51] This general principle and other rules of international humanitarian law must be read in light of the Martens Clause.[52] Although 'principles of humanity' and 'dictates of public conscience' alone may provide no firm legal basis to prohibit the use

43 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).
44 Protocol (IV) on Blinding Laser Weapons 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, 13 October 1995, 1380 UNTS 370 (entered into force 30 July 1998).
45 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).
46 Protocol (V) on Explosive Remnants of War 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, 28 November 2003, 2399 UNTS 100 (entered into force 12 November 2006).
47 Convention on Cluster Munitions, 3 December 2008 (entered into force 1 August 2010).
48 Geoffrey Duxbury *et al.*, 'Quantum cascade semiconductor infrared and far-infrared lasers: from trace gas sensing to non-linear optics', in *Chemical Society Reviews*, Vol. 34, No. 11, 2005, pp. 921–934.
49 Juan Pablo Pardo-Guerra and Francisco Aguayo, 'Nanotechnology and the international regime on chemical and biological weapons', in *Nanotechnology Law and Business*, Vol. 2, No. 1, 2005, pp. 58–59; Margaret E. Kosal, 'The security implications of nanotechnology', in *Bulletin of Atomic Scientists*, Vol. 66, July/August 2010, pp. 58–69. Cf. Robert D. Pinson, 'Is nanotechnology prohibited by the Biological and Chemical Weapons Conventions?', in *Berkeley Journal of International Law*, Vol. 22, 2004, p. 298.
50 Christopher Greenwood, 'The law of weaponry at the start of the new millennium', in Michael N. Schmitt and Leslie C. Green (eds), *The Law of Armed Conflict: Into the New Millennium*, US Naval War College International Law Studies, Vol. 71, Naval War College, Newport, 1999, p. 192.
51 Regulations Respecting the Laws and Customs of War on Land, CTS, Vol. 205, 1907, p. 277, 18 October 1907 (entered into force 26 January 1910), Article 22, reproduced in Adam Roberts and Richard Guelff, *Documents on the Laws of War*, 3rd edn, Oxford University Press, Oxford, 2000, pp. 73–82 (hereinafter 1907 Hague Regulations); Protocol Additional to the Geneva Conventions of 12 August 1949, and Relating to the Protection of Victims of International Armed Conflicts, 8 June 1977, 1125 UNTS 3 (entered into force 7 December 1978), Art. 35(1) (hereinafter Additional Protocol I).
52 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 1968 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.'

INTERNATIONAL REVIEW of the Red Cross

of particular weapons,[53] 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.[54]

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[55]

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.[56] The principle prohibiting the employment of arms, projectiles, or material 'of a nature to cause superfluous injury' (or 'calculated to cause unnecessary suffering'),[57] 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',[58] is central to the consideration of legality of nanotechnology-enabled or enhanced weapons under international humanitarian law.[59] 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.[60]

53 See, e.g., Christopher Greenwood, 'Historical development and legal basis', in Dieter Fleck (ed.), *Handbook of International Humanitarian Law*, 2nd edn, Oxford University Press, Oxford, 2008, p. 101; Antonio Cassese, 'The Martens Clause: half a loaf or simply pie in the sky?', in *European Journal of International Law*, Vol. 11, 2000, p. 187; Theodor Meron, 'The Martens Clause, principles of humanity, and dictates of public conscience', in *American Journal of International Law*, Vol. 94, 2000, p. 78. Cf. International Court of Justice (ICJ), *Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, ICJ Reports 1996*, pp. 405–409 (Judge Shahabuddeen dissenting opinion).

54 Stuart Walters Belt, 'Missiles over Kosovo: emergence, *lex lata*, of a customary norm requiring the use of precision munitions in urban areas', in *Naval Law Review*, Vol. 47, 2000, p. 140.

55 For a more detailed analysis of this issue, see Hitoshi Nasu and Tom Faunce, 'Nanotechnology and the international law of weaponry: towards international regulation of nano-weapons', in *Journal of Law, Information and Science*, Vol. 20, 2010, pp. 20, 34–43.

56 See ICRC, 'A guide to the legal review of new weapons, means and methods of warfare: measures to implement Article 36 of Additional Protocol I of 1977', 2006, pp. 18–19, available at: http://www.icrc.org/eng/assets/files/other/icrc_002_0902.pdf (last visited 30 October 2012).

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

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

59 Cf. Antonio Cassese, *The Human Dimension of International Law: Selected Papers*, Oxford University Press, Oxford, 2008, p. 214 (stating that the principle remains a 'significant source of inspiration').

60 See, e.g., Bill Boothby, 'The law of weaponry – is it adequate?', in Michael N. Schmitt and Jelena Pejic (eds), *International Law and Armed Conflict: Exploring the Faultlines, Essays in Honour of Yoram Dinstein*, Martinus Nijhoff, Leiden, 2007, p. 303.

The principle prohibiting superfluous injury or unnecessary suffering was first enunciated in the preamble to the 1868 St Petersburg Declaration,[61] but this general principle was a rhetorical expression of the drafters' inspiration, rather than of their intention to impose legal obligations.[62] It was formally adopted as a binding rule in the subsequent treaties,[63] and since then has attained the status of customary international law.[64] This principle applies universally, irrespective of the distinction between civilian and military targets.[65] The prohibition is now incorporated into the 1998 Rome Statute of the International Criminal Court as a war crime.[66] 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.[67] 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.[68] 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.[69]

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.

64 See, e.g., Jean-Marie Henckaerts and Louise Doswald-Beck, *Customary International Humanitarian Law*, Cambridge University Press, Cambridge, 2005, Vol. 1, pp. 237–244.

65 See *Legality of Nuclear Weapons Advisory Opinion*, above note 53, p. 257, para. 78.

66 See Rome Statute of the International Criminal Court, 17 July 1998, 2187 UNTS 3 (entered into force 1 July 2002), Art. 8(2)(b)(xix) and (xx).

67 This was the view generally held by states during the UN Conference on Certain Conventional Weapons in 1979–1980. See, e.g., W. Hays Parks, 'Conventional weapons and weapons reviews', in *Yearbook of International Humanitarian Law*, Vol. 8, 2005, pp. 76–82; William J. Fenrick, 'The Conventional Weapons Convention: a modest but useful treaty', in *International Review of the Red Cross*, No. 279, 1990, p. 500.

68 Yves Sandoz, Christophe Swinarski and Bruno Zimmerman (eds), *Commentary on the Additional Protocols of 8 June 1977 to the Geneva Conventions of 12 August 1949*, International Committee of the Red Cross and Martinus Nijhoff Publishers, Geneva, 1987, p. 408, para. 1428 (hereinafter ICRC Commentary). For critical analysis see, e.g., C. Greenwood, above note 50, pp. 195–199; Frits Kalshoven, 'Arms, armaments and international law', in *Recueil des Cours*, Vol. 191, 1985-II, pp. 234–235; Henri Meyrowitz, 'The principle of superfluous injury or unnecessary suffering: from the Declaration of St. Petersburg of 1868 to Additional Protocol I of 1977', in *International Review of the Red Cross*, Vol. 34, No. 299, 1994, pp. 106–109.

69 Rosario Domínguez-Matés, 'New weaponry technologies and international humanitarian law: their consequences on the human being and the environment', in Pablo Antonio Fernández-Sánchez (ed.), *The New Challenges of Humanitarian Law in Armed Conflicts: In Honour of Professor Juan Antonio*

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.[70] 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.[71] 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.[72] 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.[73] 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.[74] 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

Carrillo-Salcedo, Martinus Nijhoff, Leiden, 2005, p. 115; Éric David, *Principes de Droit des Conflits Armés*, 4th edn, Bruylant, Brussels, 2008, pp. 358–361.

70 Michael Bothe, Karl Josef Partsch and Waldemar A. Solf, *New Rules for Victims of Armed Conflicts: Commentary on the Two 1977 Protocols Additional to the Geneva Conventions of 1949*, Martinus Nijhoff Publishers, The Hague, 1982, p. 196.

71 For a similar view in the context of fragmentation of bullets, see, Robin Coupland, 'Clinical and legal significance of fragmentation of bullets in relation to size of wounds: retrospective analysis', in *British Medical Journal*, Vol. 319, 1999, pp. 403–406.

72 See Burrus M. Carnahan and Marjorie Robertson, 'The Protocol on "blinding laser weapons": a new direction for international humanitarian law', in *American Journal of International Law*, Vol. 90, 1996, p. 485. The same influence can be observed in relation to the treaties on explosive remnants of war, in particular regarding anti-personnel landmines and cluster munitions.

73 Cf. Carl E. Bruch *et al.*, 'Post-conflict peace building and natural resources', in *Yearbook of International Environmental Law*, Vol. 19, 2008, p. 58.

74 Cf. William H. Boothby, *Weapons and the Law of Armed Conflict*, Oxford University Press, Oxford, 2009, p. 364.

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 deliberatively 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

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.

76 See ICRC Commentary, above note 68, para. 1457; M. Bothe, K. J. Partsch and W. A. Solf, above note 70, pp. 347–348. This is contrasted with the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, 10 December 1976, 1108 UNTS 152 (entered into force 5 October 1978) (ENMOD Convention), which uses a disjunctive formula ('widespread, long-lasting or severe'). This Convention does not prohibit or regulate the use of nanotechnology unless it is specifically used to manipulate the environment for hostile purposes. For an analysis of this Convention, see, e.g., Jozef Goldblat, 'The Environmental Modification Convention of 1977: an analysis', in Arthur H. Westing, (ed.), *Environmental Warfare: A Technical, Legal and Policy Appraisal*, Taylor & Francis, London, 1984, p. 53.

77 See Denis Bémer *et al.*, 'Ultrafine particles emitted by flame and electric arc guns for thermal spraying of metals', in *Annals of Occupational Hygiene*, Vol. 54, No. 6, 2010, pp. 607–614.

78 See Martin Seipenbusch and Gerhard Kasper, *Recommendations to the European Commission – Transport of Nanoparticles in the Workplace Environment and Its Effects on the Size Spectrum*, Nanotransport-Project, 30 April 2008, available at: http://research.dnv.com/nanotransport/NANOTRANSPORT download/Recommendations-final-EC.pdf (last visited 30 October 2012); US EPA, above note 6, p. 33. Cf. Lan Ma-Hock *et al.*, 'Generation and characterization of test atmospheres with nanomaterials', in *Inhalation Toxicology*, Vol. 19, No. 10, 2007, pp. 833–848 (observing that as for many substances, agglomeration effects limited nanoparticle exposure).

79 See V. Stone, H. Johnston and M. J. Clift, 'Air pollution, ultrafine and nanoparticle toxicology: cellular and molecular interactions', in *IEEE Trans Nanobioscience*, Vol. 6, No. 4, 2007, pp. 331–340 (showing that ultrafine particles are found more toxic and inflammogenic than fine particles due to low solubility).

80 Michael N. Schmitt, 'Green war: an assessment of the environmental law of international armed conflict', in *Yale Journal of International Law*, Vol. 22, 1997, pp. 72–73.

INTERNATIONAL REVIEW of the Red Cross

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] Camouflaging 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]

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 '[t]o 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.

84 See generally, Tae-Woo Lee, *Military Technologies of the World*, Praeger Security International, Westport, 2009, Vol. 1, pp. 178–180.

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).

87 See generally, UK Ministry of Defence, *The Manual of the Law of Armed Conflict*, Oxford University Press, Oxford, 2004, p. 64; Leslie C. Green, *The Contemporary Law of Armed Conflict*, 2nd edn, Manchester University Press, Manchester, 2000, pp. 146–147, 186–187.

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

92 See James W. Crawford, 'The law of noncombatant immunity and the targeting of national electrical power systems', in *Fletcher Forum of World Affairs*, Summer/Fall 1997, p. 105.

93 See, e.g., J.-M. Henckaerts and L. Doswald-Beck, above note 64, Vol. 1, Rule 14.

94 For a detailed account as to why the reference to proportionality was avoided, see Lt Col. William J. Fenrick, 'The rule of proportionality and Protocol I in Conventional Warfare', in *Military Law Review*, Vol. 98, 1982, pp. 102–106; Frits Kalshoven, 'Reaffirmation and development of international humanitarian law applicable in armed conflicts: the diplomatic conference, Geneva, 1974–1977, Part II', in *Netherlands Yearbook of International Law*, Vol. 9, 1978, p. 117.

95 The literature on this subject is voluminous. See especially, Judith Gardam, *Necessity, Proportionality and the Use of Force by States*, Cambridge University Press, Cambridge, 2004, pp. 98–121.

96 See literature cited above note 8.

97 See, e.g., Christopher Greenwood, 'Customary international law and the First Geneva Protocol of 1977 in the Gulf Conflict', in Peter Rowe (ed.), *The Gulf War 1990–91 in International and English Law*, Routledge, London, 1993, p. 79.

98 See Theodor Meron, *The Humanization of International Law*, Martinus Nijhoff, Leiden, 2006, p. 67.

the proportionality calculus merely because the object is a military objective.[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'.[100]

Environmental concerns are already acknowledged in a general principle of proportionality. The International Court of Justice (ICJ) observed in its advisory opinion on *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'.[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.[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.[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

99 Henry Shue and David Wippman, 'Limiting attacks on dual-use facilities performing indispensable civilian functions', in *Cornell International Law Journal*, Vol. 35, 2002, pp. 565, 573–579.

100 Michael N. Schmitt, 'The principle of discrimination in 21st century warfare', in *Yale Human Rights & Development Law Journal*, Vol. 2, 1999, p. 168.

101 *Legality of Nuclear Weapons Advisory Opinion*, above note 53, p. 242, para. 30.

102 The provision, in full text, reads: '*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 *Denver Journal of International Law and Policy*, Vol. 28, 2000, pp. 275–277.

103 ICRC Commentary, above note 68, pp. 663–664, para. 2135.

INTERNATIONAL REVIEW of the Red Cross

scientific difficulties for the precise understanding of the nature and extent of health effects.[104] 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.[105] It is in this context that the principle of proportionality arguably finds its application in relation to environmental collateral damage.[106] 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.[107] 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.[108]

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.

104 See, e.g., Fadri Gottschalk and Bernd Nowack, 'The release of engineered nanomaterials to the environment', in *Journal of Environmental Monitoring*, Vol. 13, 2011, pp. 1145–1155; Jayoung Jeong *et al.*, '*In vitro* and *in vivo* toxicity study of nanoparticles', in Saura Sahu and Daniel Casciano (eds), above note 15, pp. 320–324 (pointing out that very few airborne exposure studies have been conducted).

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

106 Cf. Michael Bothe *et al.*, 'International law protecting the environment during armed conflict: gaps and opportunities', in *International Review of the Red Cross*, Vol. 92, No. 879, 2010, pp. 577–578.

107 M. N. Schmitt, above note 102, p. 283. A broader incorporation of environmental effects into the proportionality calculus was suggested in ICTY, 'Final Report to the Prosecutor by the Committee Established to Review the NATO Bombing Campaign Against the Federal Republic of Yugoslavia', in *International Legal Materials*, Vol. 39, 2000, pp. 1262–1263, paras. 15–22 (hereinafter ICTY Final Report). See also, Michael Bothe, 'Legal restraints on targeting: protection of civilian population and the changing faces of modern conflicts', in *Israel Yearbook on Human Rights*, Vol. 31, 2002, pp. 44–45.

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

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.

110 See J.-M. Henckaerts and L. Doswald-Beck, above note 64, Rule 15.

111 *Ibid.*, Rule 44.

112 Cf. M. Bothe *et al.*, above note 106, p. 575; Richard Desgagné, 'The prevention of environmental damage in time of armed conflict: proportionality and precautionary measures', in *Yearbook of International Humanitarian Law*, Vol. 3, 2000, pp. 125–126; Wil D. Verwey, 'Observations of the legal protection of the environment in times of international armed conflict', in *Hague Yearbook of International Law*, Vol. 7, 1994, p. 52.

113 J.-M. Henckaerts and L. Doswald-Beck, above note 64, Rule 22. Cf. W. Hays Parks, 'Air war and the law of war', in *Air Force Law Review*, Vol. 32, 1990, p. 1, at p. 159 (stating that this provision is not obligatory).

114 ICTY Final Report, above note 107, p. 1271, para. 51. See also, Anthony P. V. Rogers, *Law on the Battlefield*, 2nd edn, Manchester University Press, Manchester, 2004, pp. 120–126.

INTERNATIONAL REVIEW of the Red Cross

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.[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.[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.[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

115 See, World Trade Center Health Program: Addition of Certain Types of Cancer to the List of WTC-Related Health Conditions, US Federal Register, Vol. 77, No. 177, 2012, pp. 56138–56168.

116 See, Preamble to the 1868 St Petersburg Declaration, above note 52.

117 See, e.g., Tomislav Z. Ruby, 'Effects-based operations: more important than ever', in *Parameters*, Vol. 38, No. 3, 2008, p. 26; Edward A. Smith, Jr., 'Effects-based operations', in *Security Challenges*, Vol. 2, No. 1, 2006, p. 43; Elinor C. Sloan, *The Revolution in Military Affairs: Implication for Canada and NATO*, McGill-Queen's University Press, 2002, p. 15; David A. Deptula, *Effects-Based Operations: Change in the Nature of Warfare*, Aerospace Education Foundation, Arlington, 2001, pp. 21–22.

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.