Military Uses of Nanotechnology: An Overview of Trends in Investments, Expected Outcomes and Potential Impacts on Arms Control Regimes

Alain DE NEVE

Researcher at the Center for Security and Defence Studies (CSDS) of the Royal High Institute of Defence (RHID), Ph.D. Candidate in Political Science (Catholic University of Louvain).

Introduction

While nanotechnology (NT) has not yet enter into the mainstream, many observers and scientists believe that this new technology will become a greater revolution force[1]. Until now, NT has been essentially debated regarding the expected turn-over its related activities could generate in a distant and not so distant future. In its communication entitled *Toward a European Strategy for Nanotechnology*, the European Commission estimates that the future market for products issued from NT could rise to hundreds of billions of Euros by 2010 and to one trillion thereafter[2]. It is however only to a lesser extent that ethical, societal and health concerns about nanotechnology have been discussed.

Some observers of US Science policy do not hesitate to allege that nanotechnology is at best a "buzzword" aimed at generating support and financial subsidies. More critical views relegate NT to a great "marketing campaign" and ask:

"Is nanotechnology a fad? Prospective investors, or prospective research sponsors, want to know – and it's not too early in the life cycle of the field to ask, and answer.[3]"

---

[1] COLEMAN, K, "NanoTechnology and the Fight Against Terrorism", *Directions Magazine*, June 11, 2003, available on http://www.directionsmag.com.

[2] *Towards a European Strategy for Nanotechnology*, communication from the Commission, 2004, p. 5.

[3] COFFEE, P., "Fads and Hype in Technology: The Sargasso Sea of "Some Day Soon", in FOSTER, L. E. (Ed.), *Nanotechnology: Science, Innovation and Opportunity*, Upper Saddle River (New Jersey): Prentice Hall, 2006, p. 19.

Several experts and commentators expressed their concern as they are invited to evaluate the possibility to expect some concretes results from NT research. Yet, "*simple forms of nanotechnology are used in a few consumer products—like some new semiconductors, sunscreens, and stain-resistant trousers—but it isn't clear that such products are worth billions of taxpayer dollars.*[4]"

Curiously, expected military uses and possible security threats deriving from nanotechnology have rarely been included in debates regarding its future developments. This is highly problematic. Nanotechnology will inevitably lead to *disruptive technologies*. If such technologies could lead to the development of a new generation of weapon systems and combatants, they could also give rise to the growth of disturbing factors affecting the global military balance. Yet, such a phenomenon is not new. Military innovation, even in peacetime, has become an extension of war itself. As Tim Benbow noted, "*there are many historical examples of battles, campaigns and wars being decided by the failure of one belligerent to appreciate developments in technology and either to incorporate or to counter them.*[5]" Through history, every military-technical revolution did not only give rise to new means of warfare, it also alter – and sometimes in a dramatically way – the structure of international relations.

The objective of this paper is threefold. Fist it aims at providing a general overview of international investments in defence-oriented nanotechnology. Second, it will briefly introduce the reader to the expected mid-term and long-term military applications researches in nanosciences and nanotechnology could lead to. Finally, the paper will evoke some of the most expected risks that could be induced by nanostructured or nanomanufactured weapon systems.

Innovation in warfare: a global view

Whether NT will enhance existing weapon systems or lead advanced societies to a new age of warfare remains doubtful. Nanotechnology has not yet acquired the status of a sufficiently mature technology to allow analysts to foresee what could be its precise impact on political-military affairs in the coming decades. In a certain sense, one can argue that History is full of examples of societies that revealed themselves inept to correctly adapt to new technologies as they

[4] "The Nanotech Schism: High-Tech Pants or Molecular Revolution?", in *The New Atlantis: A Journal of Technology & Society*, No. 4, Winter 2004, pp. 101 – 103.

[5] BENBOW, T., *The Magic Bullet? Understanding the Revolution in Military Affairs*, London: Brassey's, 2004, p. 9.

developed. In that case, technology has little to do with success and/or defeats. It is, first of all, a matter of how opened are societies and their military organizations when they think about future wars and the means to win them. Williamson Murray brilliantly depicted that challenge:

"How armies, air forces, marine corps and navies think about war guides their peacetime innovations and determines the patterns of successful or unsuccessful adaptations in war"[6]

If culture matters first, it is thus reasonable to argue that:

"Whatever technological changes occur in the [present] century, the fundamental nature of war will not alter"[7]

Will nanotechnology become a new incremental innovation or will it drastically alter the way future armies will wage war? If nanotechnology can be reduced to "technical solutions" that shall be integrated in adapted political-military organizations, the magnitude of change resulting from related innovations should not be greater than in the past. It is however far more plausible that the introduction of NT-based systems will dramatically modify the structure of the military, not only by disrupting the existing global strategic balance but also by leading towards a new set of scales between humans and machines or, in the most anticipated scenarios, to a human/machine fusion.

Main NT Military-Oriented Efforts

Several major powers are making budgetary efforts in order to sustain R&D in nanotechnology with the hope to support their armed forces with new and advanced materials. However, the United States are truly the only country that has chosen to dedicate specific investments in nanotechnology-based programs for defense purposes. Yet, other powers, in Europe (with the exception of Sweden [see below]) and Asia, are conducing NT programs but returns for the military are only indirect and appear to be developed more organically[8].

---

[6] MURRAY, W., "Military Culture Does Matter", *Strategic Review*, Vol. XXVII, No. 2, Spring 1999, p. 32.

[7] *Ibid.*, p. 37.

[8] BERGER, M., "Military Nanotechnology: How Worried Should We Be?" article posted on http://www.nanowerk.com/spotlight/spotid=1015.

Military-Oriented Research in the US

For the US, maintaining technological superiority constitutes a strategic advantage. This is the reason why the Department of Defense has become a major investor in nanotechnology. Military nanotechnology programs cover a wide array of applications to improve the performance of existing weapon systems and to develop new ones. Since the 1980s, the United States has evaluated foreign developments in nanotechnology, with a special focus on Japan. Along with years, the scope has been widened. It now encompasses research policy activities in many parts of the world, including, inter alia, the European Union (EU), China and Russia. In order to facilitate foreign technology monitoring, the US National Science Foundation established a *World Technology Evaluation Center* (WTEC), initially located at Loyola College in Maryland[9]. Today, the WTEC operates as an independent governmental institution.

Since the mid-1990's, the DoD has identified nanotechnology as one of six "Strategic Research Areas". Several studies and activities were then conducted in order to compare public and private investments injected in NST research worldwide. The results provided the US public authorities with the right tools in order to develop a true national supportive policy in favor of nanotechnology. These exercises led the US authorities to launch, in 2001, a National Nanotechnology Initiative (NNI). The NNI is aimed at coordinating Federal nanotechnology research and development in the United States. Such an objective is supposed to be reached through a global sharing of goals, priorities and strategies among the various NT research programs. These efforts are to be served by a long term vision about expected opportunities and benefits that could be issued from NT. The NNI represents a genuine transversal policy dedicated to the maximization of R&D activities in NT.

Provisions figuring inside the NNI invite the several actors invested in NST R&D to restructure in order to take into account the trandisciplinary character of nanotechnology. Reorganization does not only concern academic research centers and laboratories for that it is also directed towards the private sector (encouraged to selectively engage and take part in development activities), the government

[9] FOGELBERG, H., "The Grand Politics of Technoscience: Contextualizing Nanotechnology"; in FOGELBERG, H. & GLIMELL, H., *Bringing Visibility To the Invisible*, Göteborg Universitet, Section for science and Technology Studies, STS Research Report 6, p. 35. Reports resulting from these studies and activities were i.a. *The R&D Status and Trends in Nanoparticles, Nanostructured Materials, and Nanodevices in the United States* (WTEC Workshop 1997) and *Nanostructure Science and Technology* (under the auspices of the Interagency Working group on Nanoscience, Engineering and Technology [IWGN]).

funding agencies (NSF, DOD, DOE, DOC, NIH, NASA) and the professional societies (which can operate as forum for communication and exchange). In other words, the main strength of the NNI may reside as much in a "new management philosophy" as in budgets devoted to NST.

Inside the NNI, the DoD nanotechnology program is declined into seven *Program Component Aeras* (also known as PCA). These are:

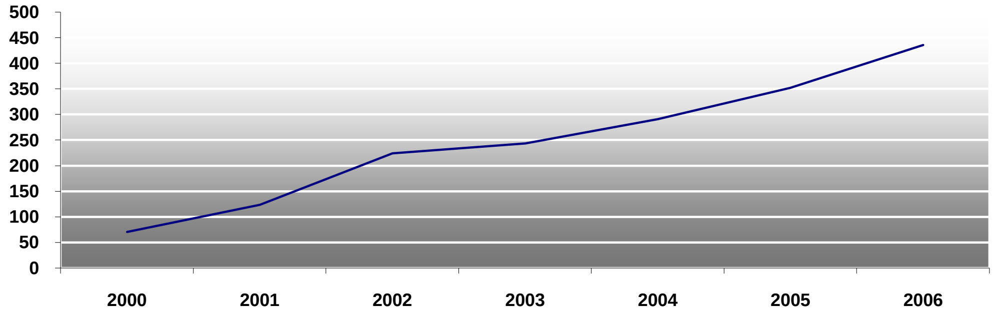
1. Fundamental nanoscale phenomena and processes;
2. Nanomaterials;
3. Nanoscale devices and systems;
4. Instrumentation research, metrology, and standards for nanotechnology;
5. Nanomanufacturing;
6. Major research facilities and instrument acquisition;
7. Societal dimensions.

When the NNI was founded in 2002, the DOD got a major share from the beginning with an amount of funding that represents ¼ of the total. It is very difficult to establish a clear panorama of the NST R&D activities funded by the Department of Defense. Most of the nano-oriented programs are managed by the Defense Advanced Research Project Agency (DARPA). In other words, the DARPA gets by far the highest share of the global NNI funding. Alongside the DARPA, other military laboratories appear to be active in the nanotechnology field. One has to underline the role played by the Army Research Laboratory, the Air Force Research Laboratory and the Naval Research Laboratory.

	2007 Actual	2008 Estimated	2009 Proposed
Department of Defense	450	487	431
National Science Foundation	389	389	397
Department of Energy	236	251	311
Department of Health and Human Services/National Institute of Health	215	226	226
Department of Commerce/National Institute of Standards and Technology	88	89	110
NASA	20	18	19
Environmental Protection Agency	8	10	15
Department of Health and Human Services/ National Institute for Occupational Safety and Health	7	6	6
US Department of Agriculture/Forest Service	3	5	5
US Department of Agriculture/Cooperative State Research, Education and Extension Service	4	6	3
Department of Justice	2	2	2
Department of Homeland Security	2	1	1
Department of Transportation	1	1	1
Total	1,425	1,491	1,527

In order to guarantee a better coherence of efforts in military nanotechnology, the United States Army in cooperation with the Massachusetts Institute of Technology decided to create, in 2002, the Institute for Soldier Nanotechnologies (ISN). The idea to join forces to develop better solutions for future dismounted soldiers dates back to 1998 when Army representatives and NSF members met together during conferences and workshops dedicated to nanotechnology solutions for defence. The ISN's mission is to serve as the Army's focal point for basic research into nanotechnology for applications to the future soldier (see below).

Figure 3: NNI Budget 2007 - 2009 (in millions of dollars)



NT Programs in Emerging and Re-Emerging Powers: China and Russia

Whether NT research programs are developed in China and Russia is no more source of speculation. Correlation of various data tends to indicate that policies intended to sustain research in the field of NT exist in those countries. Whether a military oriented approach in NT does really exist is subject to more conjectures. Available information should invite us to be extremely cautious. A key indicator to evaluate scientific investments in NST worldwide is the number of scientific publications officially released. Yet, data from the Science Citation Index tend to prove that while researchers in the US publish many more papers in the nanosciences than researchers from any other country, a more detailed picture of international scientific publications shows another reality. Global rankings change when a nanoscience is broken into different subcategories. For example, within the subfield of nanomaterials Chinese researchers take the second place behind the US[10]. While some estimations tend to suppose the effective existence of a Chinese military-oriented program in nanosciences and nanotechnology, the exact degree of budgetary investment consented by Chinese authorities remains uncertain.

On the contrary, more precise information has come from the Russian government regarding its investment in nanotechnology. According to Russian representatives, the development and use of nanotechnology and nanomaterials

[10] HULLMANN, A., "Who Is Winning the Global Nanorace?", *Nature Nanotechnology*, Vol. 1, November 2006, p. 81.

will predetermine the rate of research and development in the country. The government told the press that it would invest some $10 billion in nanotechnology development programs in the mid-term.

The Russian Rosnanotech state corporation is set to invest more than $714 million in no less than 20 projects within the next months. Rosnanotech also recently announced that it could increase its outputs to $157 billion by 2015. Currently, Russia's share is less than 0.1% of the world output in nanotechnology. This share should reach 3% by 2015, according to officials[11].

Should we expect the development of Russian military-oriented nanotechnology programs in the coming decade? According to military specialists and observers, a nanotechnology-improved weapon system has already been developed by the Russian military. The successful test of the world's most powerful non-nuclear weapon, christened "Dad of All Bombs" by Russian authorities (in reference to the US massive ordnance air blast "Mother of All Bomb" tested some days before the Iraqi campaign of 2003) showed the destructive potential of a partial nanostructured device. While the Russian bomb contains about only 7 tons of high explosives (compared with the 8 tons of explosives contained in the US bomb), it's four times more powerful because of the inclusion of a highly efficient kind of explosive developed with the use of nanotechnology. There is therefore no doubt concerning Russia's intent to develop military-oriented nanotechnology programs. It should also be added that recent Russian developments regarding UCAV technology could give new opportunities for future implementations of nanotechnology solutions.

Does the EU Have a Nanopolicy?

As an answer to the US National Nanotechnology Initiative, the European Commission decided, in 2003, to publish a communication relating to its new strategy in support of nanosciences and nanotechnology. Thought the EU seems to have a clear view of the way NST should be developed in a middle term future it took times before the EU realizes the necessity to develop a genuine strategy in the field. This is not to say that R&D policies for NST did not preexist. However, NST was certainly not recognized as a specific domain *per se*. It was then clear that one of the main challenges EU scientific authorities would have to cope with would be to correct irregularities so as to make the machinery of research and development more efficient and effective.

[11] "Russia To Invest $10 Billion in Nanotechnology in Mid-Term", *Ria Novosti*, 3 December 2008.

In the past, national policies dedicated to science and research in advanced materials and nanotechnology showed that public authorities did not take the correct measure of future applications perspectives.

In 1996, the first reports addressing the issues of nanotechnology as a European Endeavour were published. One has to mention the report *Overview of Activities on Nanotechnology and related Technologies* published by the Commission Institute for Prospective Technology Studies. It indicates that the first actions undertaken towards a European nanotechnology initiative were already adopted in the mid-1990s. However, conclusions resulting from expert's hearings stressed the need for initiatives in nanotechnology at a global level.

In 2002, the 6th Framework Program (FP6) for research and innovation was presented as an effort in order to change the situation for nanotechnology by elevating it as a European priority on its own. Two years later, a communication from the European Commission entitled *Towards a European Strategy for Nanotechnology* aimed at defining the EU approach to nanotechnology and science in advanced materials. It sought to bring the discussion on nanosciences and nanotechnology to an institutional level. In 2005, the European Commission adopted an Action Plan called *Nanoscience and Nanotechnologies: An Action Plan for Europe, 2005 – 2009*. The objective pursued here by the EC was to define a series of articulated and interconnected actions for the immediate implementation of a safe, integrated and responsible strategy for nanosciences and nanotechnology. Among the provisions included in the AP, one should particularly stress initiatives aimed at fostering industrial exploitation of R&D on NST by bringing together stakeholders to discuss best practices for commercialization, the societal, political and psychological barriers to entrepreneurship in Europe and license arrangements between industry and R&D organizations. The AP also invites investors, entrepreneurs to develop common standards even as NST research infrastructures and poles of excellence.

Succeeding the FP6, the 7th Framework Program placed a special emphasis of research in nanomaterials. Nanosciences, Nanotechnologies, Materials and New Production Techniques will be financed by the Commission for a total amount of about €3,465 millions.

Tableau 3: Budgets of the 7th Framework Program for Research and Development, 2007 – 2013 (in millions of euros)

Health	6.100
Agriculture and Biotechnologies	1.935
Information and Communication Technologies	9.050
Nanosciences, Nanotechnologies, Materials and New Production Techniques	3.475
Energy	2.350
Environnement (including Climate Change)	1.890
Transport	4.160
Socio-Economics and Human Sciences	623
Security and Space	Espace 1.430
	Sécurité 1.400

At the intergovernmental level, some programmatic efforts conducted under the auspices of the European Defence Agency aim at sustaining R&D projects with nano-centered solutions. The first Joint Investment Program (JIP) dedicated to *Force Protection* integrates research domains directly or indirectly linked to nanotechnology. A second JIP, focused on *Innovative Concepts and Emerging Technologies* (ICET), will reinforce the first investment efforts for it will look into technologies such as nano-materials and structures, remote detection and health monitoring.

Some EU National Investments

EU investments and strategies in the field of NST are not intended to substitute to national research efforts. Rather, EU supportive programs and budgets are aimed at ensuring a greater and better coherence among national initiatives. Alongside EU efforts, one has to stress some of the main national enterprises undertaken for a better understanding of molecular technologies.

The UK Ministry of Defence (MOD), for example, is also funding some military aspects of nanotechnology. These include new structured materials, electronic devices, etc. Research is mainly carried out through the Defence Evaluation and Research Agency (DERA) and corporate research programs associated to public-funded efforts. In Sweden, government authorities in charge with science policy are investing €11 million over five years in NST activities. Funds are especially focused on military purposes via the Swedish Defence Research Agency (SDRA). Activities related to nanotechnology and new structured materials can be found in a wide array of research program areas (C4ISTAR, electronic warfare, human systems, protection against CBRN and other hazardous substances, security, safety and vulnerability analysis, sensors and low observable, strike and protection). French military program FELIN, though it is not specifically conceived in order to implement nanotechnological solutions for dismounted soldiers, could well be completed with incremental nanomaterials and equipments via upgrades.

Future Military Applications of Nanotechnology

Currently, nanotechnology is evolving from the basic stage of its development into the applied research stage of technology maturity. This is not to say that real world applications of nanotechnology do not exist. These mainly break down in areas such as coatings, industrial powders, chemicals and carbon nanotubes.

Potential military applications and/or uses of nanotechnology could be far more diverse. One has to underline the fact that NT will not only give rise to genuine nanostructured weapon systems (vertical innovation). Rather, nanotechnology is expected to affect various fields of research and disciplines (horizontal innovation) including pharmaceuticals, biology, chemistry, physics, virology, etc. This is the reason why we must be very careful when discussing the expected impacts of NT in military affairs.

Among the first applications of nanotechnology, we can expect to find materials that are lighter and stronger. These will feature different properties than materials available today. In that sense, NT will first give rise to improvements in existing systems configurations. It must be underlined that such improvements will be of first importance for the defense community. Nanostructured materials will provide the defense industry with the required means to develop lighter, flexible, more agile and more resistant military platforms, including light armored vehicles, tanks, fighter jets, man-transportable micro-unmanned air vehicles (MUAV), etc. Developments in NT will ensure the manufacture of platforms that will have an ability to adapt to all types of climate conditions and environments. For example, it is more than plausible to assist, in the future, to the production of aerial platforms able to operate from land bases or sea-based carriers, regardless of the environmental constraints (maritime spindrifts, desert sand, tropical vegetation and extreme level of wetness).

Remarkable mid-term advances are expected to occur in information technologies (IT). Battle systems architectures, lightweight nanonetworks, self-assembled nanosystems will noticeably improve situational awareness capabilities. When preparing a campaign or a crisis intervention, powerful and highly capable computers will support the commander to assess data issued from various sensors should they be located on earth, sea, air or space. Network-Centric Warfare[12] concepts will undoubtedly benefit from such advancements in computing speed. Whether such capabilities will definitely erase the "fog of war" remains uncertain.

Long-term applications will induce dramatic changes not only in the use of force but also in the means the military will rely upon. Between 15 and 30 years, one can expect to assist to the development of smart chemical weapons (cf. infra), reconfigurable materials and features with a far better targeting capability.

Conventional weapons are expected to benefit from mid-term and long-term developments in nanotechnology. On-board computers in missile systems will be smaller, allowing an important reduction of missile's signatures and the inclusion of payload with increased destructiveness. Computers will also help the dismounted soldier. Thanks to sophisticated and discrete sensors (some of them being of an invasive sort), near-real or real time information about the way troops evolve on the battlefield will prove to be technically feasible.

More Powerful Computers to Come

Large-scale systems are expected to be developed for strategy planning, battle management and logistics. With NT improved computers, it is more than probable to assist to a drastic reduction of size of the various components and armament subsystems. Such an evolution could lead to the development of armaments that will be characterized by a higher lethal payload. It must be added that computers will, at the same time, become much faster and far less power-consuming (thus maybe reducing the operational tyranny of the logistic chain during military campaigns). In a longer term perspective, one cannot exclude the development of systems augmented by new level of Artificial Intelligence (AI) throughout the military. Such systems could well be embedded in all soldier equipments (rifles, glasses, uniforms, munitions, micro-robots, nanobots, etc.) and invade soldier's physiology (see below).

[12] I choose here to use the generic term of Network-Centric Warfare (NCW) while I am aware that various forms of implementation of the concept, principally in Europe, have appeared since its inception in the United States.

On a strategic level, nano-enabled systems could reveal new potentials for planners and battle-management services. Together with sensors (via smart dusts?), wireless communication components, lightweight displays, nanotechnology may well lead to the instauration of a global, if not ubiquitous, network.

Nano-Enabled Soldiers

In 2002, the United States Army, in collaboration with the Massachusetts Institute of Technology, set up the Institute for Soldiers Nanotechnologies. This joint effort is aimed at laying the ground for new solutions that will increase future combatant's survivability on the battlefield.

One of the first applications of nanotechnological solutions for the soldiers lies in the development of "ambient-intelligent networks" (hereafter AIN). An example of application of AIN is human fitness and health monitoring in which small devices, as such as cell phones or receivers, become access for various heart rate and blood monitors or calorie counters. The main advantage of AIN resides in the fact that they rely on non-invasive technologies. Otherwise, soldier-worn systems could be able to sense the state of health of the wearer and could generate rapid reactions by releasing drugs or by using small materials in order to compress the wounds. Such invasive nano-agents could also help the soldier to progress on the battlefield, should the combat environment be infected by biological, bacteriological or chemical agents. Nanostructured alert systems could trigger the rapid delivery of drugs and other medicines until search-and-rescue equips can extract the injured soldiers from the infected zone of the battlefield.

When Nanotechnology and Robotics Intersect

Missile-armed unmanned aerial vehicles (UAV) are now a widely accepted feature in modern defense organizations. Unmanned devices have been frequently engaged during crisis and combat operations since the end of the Cold War. Several research and development (R&D) programs are conducted in order to extend the technical possibilities of UAV, including the manufacturing of Unmanned Combat Aerial Vehicles (UCAV) fitted with air-to-ground and, according to some observers, air-to-air capabilities. The US Air Force (USAF) and the US Navy (USN), together with the Defense Advanced Research Projects Agency (DARPA) cooperated in a not so distant past on the Joint – Unmanned Aerial System (J-UCAS), a technological demonstrator aimed at testing both the feasibility and the validity of a UCAV for the US armed forces. The J-UCAS project was officially terminated in February 2006, leaving the industry and the defense community with doubts about the future of an unmanned aerial platform.

It must be underlined that the J-UCAS technological demonstrator mainly suffered from the disparities of views inside the USAF and between the USAF and the USN.

Eventually, the USN decided, in the second half of 2007 to launch its own UCAV program[13]. US Naval Air System selected Northrop Grumman Integrated System to develop an Unmanned Combat Air System technical demonstration (also referred to as UCAS-D). Other examples of UCAV developments can be found worldwide. European defense industries, with or without participations of states, are decisively engaged in the development of UCAV solutions for the armies. These efforts are all but structured, with the exception of some sub-systems technologies as those developed under the auspices of the European Defence Agency (EDA).

Basically, UAV and UCAV technologies are not typically nano-centered solutions for their manufacture does not exclusively depend on nanotechnology. Yet, nanotechnology could greatly improve some of the technologies that will be fitted on future UCAV and UAV solutions and thus create new operational opportunities or, at least, help the engineers to deal with some shortcomings.

More specifically, nanoelectronics will be a crucial enabler in the move toward making human beings out of the platforms. Some scientists invested in molecular computing stress the fact that by 2020 computers could have the same processing capacity as the human brain. "Dehumanizing warfare" will be a great challenge for the military. Concretely, if a pilot is taken out of an aircraft, it gives the opportunity for the conceiver to increase the payload and/or the endurance of the whole weapon system.

Once again, such a progress has nothing new. The pressure to automate war has been long under way. Some observers consider that it began in the 19th Century with the advent of accurate rifles. Their use made it clear that the practice of lining up masses of men was no longer viable. The last major military campaign *Iraqi Freedom* was maybe the best example of pilot's limits. Fighters used to fly during more than 8 hours waiting for orders of strike. Thus why not replace the most vulnerable link in the killing chain? Nonetheless, defence organizations and hierarchies have to be very cautious regarding the progressive substitution of men by machines. Recent studies conducted by experts on behalf of the Naval War College have tended to demonstrate that pilots feel generally reluctant when they

---

[13] GOODMAN, K. C., « Navy Launches Its Own UCAV Program », *Journal of Electronic Defense*, Vol. 30, No. 9, pp. 16 – 17.

are asked about the most transformative changes that could occur in their job. Service cultures, military ethos, group cohesions are not just theoretical concepts.

Increased Survivability and Adaptive Systems

An increasing of endurance and survivability could also be obtained thanks to the adjunction of nanomaterials. Tailor-made nanomaterials will enable unmanned and manned vehicles to be stealthy across the full spectrum, including infrared and ultraviolet. Smart materials will also be able to diagnose themselves in real time of a malfunction of the system. Failure mechanisms in most materials first appear at the nanometer size scale.

Problems associated with corrosion and usury could be overcome for nanomanufactured materials will show much more resistance given their new structure. Such improvements could generate appreciable cost savings when developing new weapon systems and platforms. Nanomaterials should allow program managers to extend the number of versions of a specific program without risking cost overruns, at least theoretically.

Nanotechnology and Arms Control Regimes

Opportunities resulting from future advances in nanotechnology could well be tarnished by new dangers. One of the greatest threats could stem from the occurrence of new powerful technologies allowing the military to rely on unprecedented forms of destructive capabilities. Be the hypothesis of future molecular manufacturing (developed by Eric K. Drexler) accepted or not, one must admit that military applications of nanotechnology will severely impact on existing military balance.

As far as conventional forces are concerned, the prospect of revolutionary advances in military capabilities will stimulate competition given the possibility for one nation that gained sufficient lead in molecular nanotechnology to totally disarm any potential competitors.

Whether nanotechnology could lead to further qualitative changes in the conception of nuclear weapons remain unsure. Existing sophisticated guidance systems will only benefit from further miniaturization. These enhancements, however, will not change the minimum requirement for a nuclear weapon: that is the quantity of kilograms of fissile materials.

Yet, auxiliary systems included in the development of protection measures for nuclear weapons could dramatically jeopardize the military balance as much between nuclear powers as between nuclear powers and conventional powers.

Nuclear deterrence is, for a large part, based upon the relative vulnerability of defensive systems. Any enhancement of one state's silos or missile vectors could affect the deterred state's calculations. Moreover, advanced nanotechnology could facilitate extensive civil defense constructions and provide counterforce weapons undermining the nuclear "balance of terror". In other words, any technological breakthrough that could lead to more robust basing modes and the development of new delivery systems designed to penetrate defenses could impact on nuclear deterrence inherent stability.

Convergences between nanotechnologies and biotechnologies, combined with genomics, proteomics and combinatorial methods in both chemistry and biology, should lead to new therapeutic agents of greater specificity and safety. However, hostile applications of these converging technologies should be seriously considered. Abovementioned applications of nanotechnology for dismounted soldiers gave some examples of future diagnosis capabilities the military could rely upon. It could be possible for future adversaries to proceed to hostile manipulations of the human nervous system. Disabling biochemical agents attacking the very core of the neural circuitry, incapacitating agents or agents specifically designed for interrogation of prisoners are some of the most predictable features that will result from the offensive applications of the new biology.

Recent advances in the understanding of pathogenesis open the door for military applications. These could lead to weapons with increased lethality or augmented effects on the physical integrity of soldiers as citizens. Such means could take many forms, as for example, genetically engineered pathogens capable of evading diagnosis and treatments, exceptionally lethal pathogens, pathogens with enhanced contagiousness and environmental stability.

The greatest risks could specifically come from the development of pathogens spreading disease faster. Currently, existing pathogens are confronted with a natural limit for they are just able to spread from host to host. The "new biology" could overtake such a limit and pave the way to the creation of enhanced engineered diseases able to persist over long periods of time in an aerosol form. One of the main reasons why states in the past used to demonstrate reluctance when considering the use of biological weapons was the short persistence of pathogens after their weaponization. Once again, the "new biology" could develop the tools to increase the perseverance of viruses and microbes once these are weaponized.

Among longer term dangers, one can expect the making of synthetic prions and viruses, the development of pathogens with incomparable virulence, the creation of cell-like vectors for biochemical agents, the manufacturing of stealth pathogens or genotype-specific and ethnic-specific pathogens

Conclusion

Like any other technological revolution, promises and opportunities driven by scientific advances in nanotechnology must be balanced with the new vulnerabilities future breakthrough might create. It would be a terrible mistake to wait for the first applications of nanotechnology before initiating prospective studies regarding their impact on international security.

Past revolutions in military affairs showed that the effects induced by new technology were largely underestimated and incorrectly anticipated. New control and verification mechanisms have to be conceived and should not rely on incremental adaptations of the existing ones.