NATOs Parlamentariske Forsamling (2. samling)
NPA alm. del - Bilag 33
Offentligt

SCIENCE AND TECHNOLOGY

065 STCMT 05 E
Original: English

NATO Parliamentary Assembly

SUB-COMMITTEE ON PROLIFERATION OF MILITARY TECHNOLOGY

THE SECURITY IMPLICATIONS OF NANOTECHNOLOGY

DRAFT REPORT

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International Secretariat 15 April 2005

* Until this document has been approved by the Science and Technology Committee, it represents only the views of the Rapporteur.

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I. DEVELOPMENT OF NANOTECHNOLOGY

1. Nanotechnology (NT) can be described as the manipulation of materials or devices at the nanometer scale (one billionth of a meter), often at the level of individual atoms and molecules. NT is considered to be the next fundamental revolution in technology, because it enables the exploitation of distinct laws of physics, different from those of classical Newtonian physics. At the nanoscale, the laws of quantum mechanics are applied. The importance of gravity diminishes, while the importance of forces existing among elementary particles increases.

2. It is a well-known fact that the arrangement of atoms may change the properties of materials. For instance, a diamond and a piece of coal consist of identical coal atoms with different arrangement, in the same way as an analogical difference exists between a crowd of people and an orderly column of soldiers. Re-arranging atoms may result in materials becoming stronger, lighter, more energy-efficient, or a better at conducting electricity. The most illustrious example is carbon nanotubes, discovered in 1991 that possess unusual strength and electrical properties.

3. Another way to alter the properties of materials is to add small amounts of nanoparticles. At the nanoscale, particles behave differently – they might have another colour or different electric characteristics than when in bulk amount. Thus, for example, by adding nanoparticles of clay to a polymer used to wrap power lines, one might increase material's strength and reduce it flammability.

4. Perhaps the most interesting avenue of NT development is its potential to revolutionalise manufacturing, introducing a new concept of assembly where products are constructed from the bottom-up—that is, from atoms and molecules—to create objects of virtually any volume and shape. While this revolution is still far in the future, scientists today have yet to find any laws of physics that would prove such developments impossible.

5. The development of NT was predicted as long ago as 1959 by Richard P.Feynman, widely seen as one of the greatest physicists of the 20th century. In his famous presentation "There's Plenty of Room at the Bottom" to the American Physical Society, he stated that "the principles of physics, as far as I can see, do not speak against the possibility of manoeuvring things atom by atom." More than twenty years later, in 1986, K. Eric Drexler coined the term "nanotechnology" and advocated its feasibility in *Engines of Creation: The Coming Era of Nanotechnology*, which would later become a classic.

6. Today, NT is a reality. Scientists succeeded in producing nanomaterials in a number of ways. The most popular technique remains “downsizing,” or creating a nanomaterial from top down (for example, by etching a silicon microchip). Conversely, an example of a “bottom-up” approach would be the synthesis of carbon nanotubes using techniques like Chemical Vapour Deposition, which is familiar to all chipmakers. Nanoparticles can also be manipulated individually by special tools, such as the scanning tunnel microscope (STM) and the atomic force microscope (AFM), and their improved versions. Yet another method is to harness the power of DNA to create a self-assembling nanoscale transistor, the building block of electronics.

7. However, construction by moving individual atoms is not yet suitable for mass production, as the process remains cumbersome and time-consuming. Therefore, a number of NT researchers, led by Drexler, have backed the idea of *molecular nanotechnology (MNT)*, which might be even considered as the only true NT. In a MNT, objects would be constructed by tiny nanorobots, which would also be capable of assembling themselves, just like cells in the organic world. The MNT could dramatically change a pattern of manufacturing, enabling mankind to produce virtually any quantity of high-quality products in an inexpensive and ecological manner. However, such self-replicating nanoassemblers have yet to be invented. Moreover, scientists like Nobel Prize winner Richard Smalley have questioned their feasibility. Currently, a different model of three-dimensional

“convergent assembly” looks more plausible – products could be created from bottom-up on different levels of assembly lines. That is, the smallest elements would be assembled into larger parts, these larger parts in turn can be assembled into still larger parts, and so forth, until the final product is complete. The elements would be assembled by robots of different sizes, depending on the level of assembly line.

8. A number of countries and private companies are investing heavily in NT research. According to the assessment of Lux Research, a US nanotechnology consultancy, the total spending on nanotechnology R&D worldwide exceeded $8.6 billion in 2004. Federal funding for nanotechnology R&D has increased sixfold from 1997 to 2004. The US government will spend almost $1 billion within the framework of its National Nanotechnology Initiative (NNI) in 2005, making NT the largest American scientific programme funded from the federal budget—surpassing even the Human Genome Project by a considerable sum. Japan is also investing aggressively, as well as other biggest European and Asian economies. Developing countries such as India, China, South Africa and Brazil, have also joined the race. While government investment in NT has, so far, exceeded that of private companies, Lux predicts that this proportion is likely to change in the future.

9. At this point, NT's practical application is mostly limited to producing computer chips, chemicals and precision manufacturing. Enhanced sunscreens, improved cosmetics, stronger tennis rackets, self-cleaning windows, fuel additives, more sensitive optics, more powerful computers –are only few examples of growing list of practical NT applications. Many scientists believe that the use of NT will increase dramatically within next decades, spreading into practically all areas of life. According to the prediction of the British Royal Society and the Royal Academy of Engineering, NT will noticeably improve a range of products within next few years. Aside from its revolutionary implications for manufacturing, NT has the potential to effect substantial changes in a number of fields, including medicine, IT, energy policies, and military. While NT enthusiasts believe it will eventually be able to eradicate the most acute problems of the humanity, such as famine, pollution, and fatal diseases, others warn of possible misuse or side-effects that could result in immense disasters. Given the magnitude of NT's potential, the possible effects of NT-driven innovation should be seriously addressed by society and politicians.

II. POTENTIAL NON-MILITARY ADVERSE EFFECTS OF NANOTECHNOLOGY

10. A number of scholars, impressed by the revolutionary nature of NT, have already initiated a far-reaching discussion on its possible negative effects. Besides the potential “hard” security implications—which will be addressed in the next chapter of this report—the misuse of NT could also harm the environment, society and individual human beings.

- ***Effects on environment. "The Grey Goo"***

  The potential impact of the environment raises exceptional concerns, as nanoparticles may constitute whole new classes of pollutants. As long as nanoparticles are embedded in common materials (as most of them are in contemporary nanoindustry), they are unlikely to pose any particular environmental threat. However, as NT advances in the future, larger quantities of pure nanomaterials could be produced. Risks involve the uncontrolled release of nanoparticles, whose potential effect on ecosystems, the environment and the food chain remains largely unexplored and untested. The most drastic scenario of possible adverse effects on the environment - the grey-goo scenario - was introduced by Drexler, and it maintains that molecular NT would one day become a reality, and most of manufacturing would be done by tiny nanorobots. These robots would also have to be self-replicating, and Drexler warned that their replication may get out of control. These autonomous nanorobots could rapidly convert the whole global natural environment into replicas of themselves, the "grey goo", consisting of the "nanomass". Such a scenario is also termed the "global ecophagy". Many scientists are extremely sceptical about the plausibility of such a scenario. As yet, science does not know how to build a self-replicating robot. It is not clear, for example, how those robots would obtain the energy to survive. However, following the precautionary principle, one should not disregard concerns regarding nanorobots as long as they have not been refuted for fundamental or technical reasons.

- ***Toxicity of nanoparticles***

More realistic concerns are related to the potential toxicity of nanoparticles. Indeed, in the realm of the nanoworld, the surface/volume ratio of particles is considerably higher that in bulk materials, thereby making them far more reactive and potentially hazardous. Being so tiny, these particles could be able to penetrate cells, including blood and brain cells, adversely affect them, and disturb human immune system. Carbon nanotubes, for instance, are similar to asbestos fibres, and could pose similar risks to lung health. In its famous report, Britain's Royal Society urged a thorough examination of the toxicity of nanomaterials and recommended that they be regulated as new chemicals under existing UK and EU legislation. However, Britain's Royal Society also pointed out that nanoparticles have been used for years, in areas such as computer technology or fuel additives, without causing any harm. The toxicity of nanoparticles could, on the other hand, have positive effects, most notably in medicine. For example, the ability to penetrate cell walls of human body could be used to deliver drugs to certain locations with unprecedented accuracy. Nanodevices could also target and selectively destroy cancerous cells. Still, more information about the toxicology of nanomaterials is urgently needed.

- ***Human body manipulation***

This controversial issue is likely to have significant ethical implications. Tiny nanoimplants might be designed in order to improve human body performance. Enhancing human brain performance is a particularly delicate issue. While the neuro-functional nanodevices may help healing paralysed people with spinal cord injuries, their emergence would inevitably stir passionate discussions about "melding of man and machine". The specific regulations should be adopted by the society in order to keep these developments under public control.

- ***Nano-divide***

Many nations are already witnessing an IT divide that correlates with inequality in the distribution of wealth. This gap is likely to be exacerbated by the nanotechnological revolution, forming a so-called "nano-divide." The transition from a pre-nano to post-nano world could be very traumatic and could worsen the problem of haves vs. have-nots. Such differences are likely to be striking. The National Science Foundation (NSF) supports these sentiments: "Those who participate in the nano revolution stand to become very wealthy. Those who do not may find it increasingly difficult to afford the technological wonders that it engenders."

- ***Privacy***

The miniaturisation of technology, facilitated by nanotechnology, is likely to lead to emergence of super-small and virtually invisible video cameras, microphones and transmitters. Thus eavesdropping and observing people without their consent could become significantly easier, consequently seriously jeopardising their right to privacy.

11. Societal and environmental implications of emerging NT have already attracted attention from various pressure groups and NGOs. Some groups increasingly call for a complete

moratorium on the use of nanoparticles: for example, the Corporate Watch—a British advocacy organization—produced a report on the "dark side of nanotech: hazardous substances, military applications and a huge leap in corporate power". Debates can significantly influence broader public opinion, as was in the case of genetically modified (GM) food.

12. However, there are certain reasons to believe that NT could be accepted easier than GM food. Many environmentalists see potential environmental benefits of NT – for instance, in improving water decontamination techniques, or bringing down the cost of solar cells. Social justice groups may find that NT could be a unique tool to fight poverty and disease. Also, many developing countries—including China, India, Brazil—are heavily engaged in nanotechnology.

III. MILITARY USES OF NANOTECHNOLOGY

13. While most of the debate over NT focuses on its prospects for informatics and medicine, potential military applications of NT lack proper public attention, despite the fact that NT is becoming increasingly important for military strategists. The funding of military NT makes up a substantial share of total NT funding.

14. The United States is the leader in military R&D of NT. Indeed, the US military has been engaged in this field since 1980s, focusing on ultra-submicron electronics and scanning-probe microscopy. In 1996, NT was established as one of six strategic research areas for defence. Accordingly, between 25 and 30% of the United States National Nanotechnology Initiative (NNI) funding has gone to the US Department of Defence (DoD) since NNI's establishment in 2000. In 2005, the DoD is due to receive $276 million for NT, while the Department of Homeland Security will receive an extra and $1 million for this purpose, accounting for approximately 28% of the total US NT budget. The US military R&D is focusing on the development of miniature sensors, high-speed processing, unmanned combat vehicles, improved virtual-reality training, and enhancement of human performance.

15. The UK Ministry of Defence (MOD) is also engaged in military R&D of NT, and allocates approximately £1.5 million per annum to this purpose. Sweden has invested 11 million euros over 5 years in military NT R&D, the EU had budgeted €65 million in 2004-2006 to enhance the European industrial potential in the field of security research. Even though this does not specifically mention NT, some of the areas contain NT implications.

16. Most of military NT is still in R&D level. According to Dr. Jürgen Altmann, one of the most prominent researchers of military NT, it will take between 5 an 20 years for the applications of this research to arrive. One can expect that NT-based *soldier-worn systems* will be introduced in the near future. In 2002, the Institute for Soldier Nanotechnology (ISN) was created at the Massachusetts Institute of Technology (MIT), with a five year grant of $50 million from the US Army grant. The goal of this research centre is to greatly enhance the protection and survival of the infantry soldier, using NT to create a bulletproof battle suit. US army planners are hoping to lighten the load that soldiers carry into battle. These systems could also monitor the state of health of the wearer, improve stamina and reaction, ease or even heal injuries, improve communication abilities, increase soldier's protection against biological or chemical weapons.

17. Potentially, NT could dramatically improve warfare technology. *Lighter, stronger, heat resistant nanomaterials* could be used in producing all kinds of weapons, making military transportation faster, strengthening the armour and saving energy. Earth penetrators could be created using nanomaterials rather than nuclear material. Qualities of nanomaterials can be used for better camouflage.

18. Significant breakthrough in *electronics*, encouraged by NT, could result in the creation of smaller, but very powerful computers, very small sensors and other devices that could be used by the military in a number of ways. Information could be stored and analysed more efficiently, intelligence and surveillance capabilities could increase considerably by using nanosensors, precision of projectiles could reach extreme accuracy, communication systems could become much more sophisticated, as well as virtual reality systems for training. Tiny sensors or even nanocomputers could be embedded in various military items, munitions, projectiles or uniforms, thus making them “smart”. Some more futuristic visions even foresee development of autonomous fighting robots and military use of artificial intelligence, enabled by the development of NT.

19. It is debatable whether NT could bring significant changes to *nuclear weapons*, as the laws of physics would still require a critical mass of uranium or plutonium. NT, however, might be used to improve arming or triggering systems of nuclear weapons. On the other hand, Dr. André Gsponer, Director of Geneva-based Independent Scientific Research Institute, argues that NT can actually contribute to miniaturisation and safety of nuclear bombs, by offering heat- and radiation-resistant materials. Thus NT might be used to create the fourth-generation nuclear weapon, i.e. low-yield “clean” fusion-fuelled nuclear bomb, which would contain no, or very little, fissionable material, and therefore would cause no radioactive fallout after detonation. These nukes could potentially be used in earth-penetrating missiles.

20. The potential for NT innovations in *chemical and biological weapons* is particularly disquieting, as NT can considerably enhance delivery mechanisms of agents or toxic substances. The ability of nanoparticles to penetrate the human body and its cells could make biological and chemical warfare much more feasible, easier to manage and direct against specific groups or individuals. Dr. Sean Howard, one of the most eminent scholars of NT security implications, has even called the threat of chemical and biological warfare a “real nano goo”.

21. On the other hand, NT offers tools to effectively and profoundly strengthen homeland security policies, aimed at fighting the proliferation of biological and chemical weapons. Sensitive, selective and inexpensive NT-based sensors could detect and bind components of chemical, biological or radiological weapons on the atomic or molecular level, thanks to the large surface/volume ratio of nanoparticles. This is very important, as some agents can be lethal even in minuscule quantities. Chemical and biological defence systems with nanosensors could be placed in public places, such as schools or government buildings, public transportation systems, military assets, and border-crossing sites. Finally, nanodevices could also be used to decontaminate places or individuals affected by chemical or biological weapons.

IV. IMPLICATIONS ON MILITARY STRATEGIES AND THE BALANCE OF POWER

22. The effects of NT on military strategies, as well as possible implications for existing international arms-control agreements, receive inappropriate attention from contemporary thinkers. Only few publicly available studies have been produced on this issue, with those from Dr. Altmann, Sean Howard, André Gsponer among the most oft-cited.

23. In 1995, Admiral David Jeremiah, former vice chairman of the Joint Chiefs of Staff, stated that "military applications of molecular manufacturing have even greater potential that nuclear weapons to radically change the balance of power." Indeed, states that possess more efficient, NT-based powerful data-processing systems and all-pervading sensor nets can obtain significant advantage in the age of information technologies and warfare. *Arms races* are to be expected. In years to come, Dr. Altmann predicts that the US will remain in the lead, though some states will follow just a few years behind. According to him, “in anticipation, the USA will work on countermeasures at the early stage. Others might react by increased reliance on asymmetric warfare, including attacks against infrastructure or using weapons of mass destruction.”

24. Changes in *military strategy* will thus be inevitable. Dr. Altmann warns that military decision-making could become increasingly autonomous with the development of NT, because “waiting for human pondering could lead to clear disadvantages. Unintended action-reaction cycles might evolve between opponents/ systems of warning and attack.” With respect to the effectiveness of NT-enabled defence vs. offence, Dr. Altman sees no indications of defence supremacy, and therefore "counter-attack and preventive attack will likely play an important role in armed conflict."

25. If the molecular NT scenario of self-replicating nanomachines becomes feasible, these dangers could be significantly exacerbated. Dr. Altmann describes such a scenario in frightening terms: “partly as a result of their smallness, but mainly owing to their potential for self-replication and the production of additional weapons on site, nanorobots would create extreme uncertainty. Pre-deployment against an opponent would be easier. The pressure to act fast and to use automated decision-making would grow. Unintended action-reaction cycles could work on all levels, from molecules to large-scale decision-making. Motives for preventive attacks would exist for both technologically leading and technologically lagging powers. Molecular NT would also create unknown arms-race levels as a result of attempts to maintain or increase a technological advantage, or to catch up. The urgency would be greatly increased if one assumes capabilities for fast-growing autonomous military production. In theory, the very first user could achieve a runaway advantage, with ensuing world dominance”.

26. Some analysts believe that nanoweapons could replace nuclear weapons as new tools of *strategic deterrence*. According to Scott Race of RAND, the potential of NT lies in a greater range of options for the military responses to aggression:

27. ”At nuclear conflict levels, accurate nanocomputer guidance and low nanomachine production costs would accelerate current trends in the proliferation of "smart munitions." Rather than requiring nuclear weapons to attack massive conventional forces or distant, hard targets, NT enhancements to cruise missiles and ballistic missiles could allow them to destroy their targets with conventional explosives. Conventional explosives themselves might be replaced by molecular disassemblers that would be rapidly effective, but with less unintended destruction to surrounding buildings and populations. President Reagan's goal of making nuclear weapons ‘impotent and obsolete’ could be reached not by space-based defences, but by terrestrial nanoweapons making nuclear weapons irrelevant.”

28. Mark Avrum Gubrud of the University of Maryland goes even further, claiming that traditional nuclear weapons make full-size war “obsolete” due to the impossibility of attaining and sort of “meaningful victory”. In case of NT, however, deterrence becomes obsolete, “as it will not be possible to maintain a stable armed peace between nanotechnologically armed rivals.”

29. As was mentioned in the above chapter, NT will permit *chemical and biological warfare* to become more feasible and effective. Even though this kind of warfare is considered immoral and prohibited by international conventions, NT will provide qualitatively new improvements that are likely to attract the attention of rogue elements. At this stage, it is unclear whether the countermeasures enabled by NT would prove effective enough to diminish this threat.

30. On a *tactical* level, NT could notably reduce the need for troop presence, largely thanks to the potential development of nanoscale sensors. According to William Schneider, chairman of the Defense Science Board, "nanoscale sensors have the potential to dispel the fog of war. Richness in sensors allows commanders to have a complete picture of the tactical battlefield.” S.Pace of RAND adds to this by stating “nanocomputers may allow more capable surveillance of potential aggressors. The flood of data from worldwide sensors could be culled more efficiently to look for truly threatening activities. In low-intensity warfare, intelligent sensors and barrier systems could isolate or channel guerrilla movements depending on the local terrain. In conventional theatre war,

nanotechnology may lead to small, cheap, highly lethal anti-tank weapons. Such weapons could allow relatively small numbers of infantry to defeat assaults by large armoured forces."

31. Regardless of changes in technology, however, *conventional forces* such as air, naval, and ground forces will not vanish, as they will still be needed to perform their specific functions that they are uniquely suited to. The laws of physics, for instance, limit the mobility of very small objects. In order to destroy large targets, one will still need massive munitions and carriers. Thus, one could expect development of the mixture of macro- micro- and nanoweapons.

V. IMPLICATIONS ON INTERNATIONAL NON-PROLIFERATION AND ARMS CONTROL REGIMES

A. PRECAUTIONARY AND LIBERTARIAN APPROACHES

32. NT poses both great opportunities and certain risks. How should nation states and the international community deal with the emergence of these opportunities and risks? What steps should be taken to amend the existing non-proliferation and arms control regimes? In NT-related literature and be roughly grouped in two different approaches – one that calls for moratorium on NT R&D—or even a permanent ban—an another that advocates further development of NT and all of its potential benefits. These two approaches have been labelled, respectively, "precautionary" (or "sanctuary") and "libertarian" (or "pro-progress").

1. Precautionary approach

33. The precautionary principle, in its strict sense, forbids action if there is any risk of a major disaster. Even if benefits could be significant, the very possibility of major disaster is seen as a sufficient reason to postpone any action, regardless of the costs. In other words, this principle follows the Hippocratic Oath: "First, do no harm."

34. The most prominent spokesman for the precautionary view is Bill Joy, despite the fact that he himself is the founder of Sun Microsystems. In April 2000, in his famous article in *Wired* magazine with the title "Why the Future Doesn't Need Us", Bill Joy rigorously advocated the need to withhold development of 21st century technologies, such as genetics, NT and robotics. His core argument was that these technologies, unlike cumbersome weapons of the past, can be potentially exercised by irresponsible small groups or even individuals. Joy warns, that, with NT, traditional threats of weapons of mass destruction are amplified by knowledge-based mass destruction (KMD): "They will not require large facilities or rare raw materials. Knowledge alone will enable the use of them." The menace of KMD, according to Joy, is greater than that of traditional WMD, since it promises "surprising and terrible empowerment of extreme individuals."

35. Joy suggests that we "relinquish pursuit of that knowledge and development of those technologies so dangerous that we judge it better that they never be available", noting that he, too, believes in "the pursuit of knowledge and development of technologies; yet, we already have seen cases, such as biological weapons, where relinquishment is the obvious wise choice." He has called for scientists and engineers to take a pledge, similar to Hippocratic Oath, to refrain from developing technologies with potential of mass destruction.

36. Joy's concerns were reiterated by a Canadian environmental activist group Action Group on Erosion, Technology, and Concentration (ETC Group). In August 2002, the ETC Group called for a worldwide moratorium on R&D and engineered nanomaterials until there are specific protocols of work safety were introduced. They emphasized that data about the potential adverse implications is not sufficient, and called for specific regulatory policies.

2. Libertarian approach

37. This view holds that certain risks are unavoidable in technological development, and that the decision of whether to proceed with this development should be based on assessment of potential costs, benefits, and risks. Advocates of NT believe that a ban or moratorium on R&D could actually be counterproductive, in that it would prevent risks from being scientifically assessed and (potentially) alleviated. The Center for Responsible Nanotechnology (CRN) warns that "inaction on the part of responsible people could simply lead to the development and use of molecular manufacturing by less responsible people. Lack of understanding of the technology will leave the world ill-equipped to deal with irresponsible use."

38. One of the most prominent advocates of the "libertarian" view is Freeman J. Dyson, now retired, having been a professor of physics at the Institute for Advanced Study in Princeton for most of his life. Dyson has argued that Mr. Joy ignores "the long history of effective action by the international biological community to regulate and prohibit dangerous technologies." Dyson also opposed censorship of scientific inquiry, either by international or national authorities.

39. In June 2004, NT experts from 25 countries met in Arlington, Virginia to establish the International Dialogue on Responsible Research and Development of Nanotechnology. At this meeting, the scientists present agreed that NT could be developed responsibly and that no moratorium should be imposed. Even the ETC Group, although it has not withdrawn its call for a moratorium, seemed encouraged by responsible attitude from scientists as well as governments.

B. CHANGING ARMS-CONTROL REGIMES?

40. Most experts agree that the emerging field of NT is likely to have implications with respect to existing arms-control regimes. There are fears that the NT-enabled miniaturisation of weaponry and relative items will make the proliferation easier, as well as that existing regulatory regimes might not encompass some of newly developed military-related NT products. The international community, therefore, will find itself under growing pressure to cope with this problem—either in "precautionary", or "libertarian" manner—by adjusting existing agreements introducing new ones, or both.

1. Adjusting the existing treaties

41. First and foremost, as Dr. Altmann points out, the *Biological and Toxin Weapons Convention* might be undermined by introduction of new agents. He suggests that the Convention be supplemented with "a clarifying interpretation that (NT-enabled) microscopic systems that can enter the body and are partly or fully artificial are included". Also, your Rapporteur shares completely Dr. Altmann's strong insistence on a pressing need to conclude a protocol on verification and compliance measures for BTWC in order to ensure the effective implementation of the Convention.

42. The *Chemical Weapons Convention* should be mentioned here as well, as the difference between biology and chemistry is blurred in the realm of nanotechnology. This Convention, according to Dr. Altmann, should be amended by concluding "a clarifying interpretation that for (NT-enabled) agents that are smaller than cells and damage life processes within cells any kind of damaging action counts as "chemical action" under Article 2. CWC is supported by rather intrusive verification mechanisms."

43. Your Rapporteur believes that NT will provide the means (i.e. nano-enabled verification tools, such as nanoscale sensors) to reinforce these conventions.

44. Gsponer indicates that NT-enabled fourth-generation nuclear weapons (low-yield, "clean" and usable in tactical fight) can potentially be developed without actually violating the Comprehensive Test Ban Treaty (CTBT).

45. With respect to conventional forces, NT-enabled miniaturisation and automation could potentially offer possibilities to circumvent the Treaty on Conventional Armed Forces in Europe (CFE) with the use of new weapons like autonomous microrobots, unmanned vehicles, or electromagnetic guns below 75mm-calibre threshold for tanks, as Dr. Altmann specifies. He also warns that NT-enabled autonomous fighting systems might not reliably recognize non-combatants or combatants *hors de combat*, thereby violating international laws of warfare.

2. New international initiatives

46. Some analysts, such Dr. Altmann, Howard and Gubrud, believe that, in order to properly prevent the hazardous implications of NT, the international community should introduce new multilateral agreements.

47. Howard advocates the need to conclude an Inner (atomic and molecular) Space Treaty, in addition to the Outer Space Treaty of 1976. Howard has drafted two versions of such a treaty, one based on "libertarian" and another on "precautionary-sanctuary" approach. In the "libertarian" version, parties would agree that "Inner space shall be free for exploration and engineering by all states without discrimination of any kind", but they would commit to "refrain from developing, testing or deploying any atomically-engineered objects carrying nuclear, chemical, biological, or any other kinds of weapons of mass destruction, or from installing such weapons in any apparatus or device in any environment whatever. Inner space shall be used by all states parties to the Treaty exclusively for peaceful purposes." The draft treaty also contains clauses on verification measures, such as observation of activity, notification and transparency of activities and inspection of facilities.

48. The “sanctuary” version of Howard’s draft treaty, called "Treaty on the Prohibition of Nanotechnological Exploration and Engineering of Inner (Atomic and Molecular) Space", states that NT opens " new and enhanced means of mass destruction" and "poses a grave and irreducible threat to all of humanity and the biosphere". Therefore, parties commit to "to refrain under any circumstances from engaging in, supporting, or encouraging any activities under their control and jurisdiction involving or relating to the nanotechnological exploration and engineering of inner (atomic and molecular) space." The draft treaty would also establish an "Organisation for the Prohibition of Nanotechnology (OPN)" to enforce the prohibition.

49. Dr. Altmann is another firm advocate of preventive arms control. He praised earlier efforts of the international community to limit specific developments in military technology before it is too late. For example, the nuclear test ban treaties of 1963 and 1996, the Anti-Ballistic Missile Treaty (ABM) of 1972, the Biological and Toxin Weapons Convention (BTWC) of 1972, Chemical Weapons Convention (CWC) of 1993, and the Protocol on Blinding Laser Weapons of 1995.

50. Dr. Altmann suggests that new international regulations dealing with emerging military NT include some essential restrictions:

- Unequivocal ban of autonomous “killer robots” and unmanned mobile killing systems in general, based on the principle that weapons should not be aimed or released without human decision.
- Complete ban of metal-free small arms and munitions, starting at the development stage, for they are difficult to detect, and thus more exposed to proliferation.
- Complete ban of missiles below a certain size limit (0.2-0.5 m)

- Complete ban of self-contained sensor systems below a certain size limit (3-5 cm)
- Comprehensive ban on space weapons of all kinds

51. New, NT-related clauses in international law should be supported by a stringent verification mechanism, including on-site inspections, notifications, checks on national legislation, medical examinations, and usage of powerful computers and sensors.

52. Dr. Altmann suggested that the United States, as it has achieved by far the advancements in the field of NT, take the initiative in setting this new international regime. Because it is unlikely that the US will face a significant technological challenge in this area from any country in the world, it is in a unique position of being able to unilaterally restrain from augmenting its NT-based military capabilities without having its security interests threatened.

53. International regulations alone, however, will not be enough. In order to develop a cohesive universal mechanism to cope with the challenges of NT, appropriate actions should be taken on the levels of nation states and scientific communities.

C. NATIONAL LEGISLATION

54. Even though NT was born in nuclear weapons laboratories, its ultimate goal is to bring benefits to humanity. NT products are expected to have a wide range of civilian applications that will need to be dealt by national legislations. Close co-ordination between national and international regulations is necessary, as a number of NT products can be of dual – military and civilian – use. Examples could be nanosensors or nanomaterials with extraordinary characteristics, as well as cell-penetrating nanocapsules applicable both in medicine and biological/chemical warfare.

55. In 2001, your Rapporteur addressed the issue of NT in his *Special Report on Emerging Technologies and Their Impact on Arms Control and Non-Proliferation*, which advised governments and relevant international organisations to “pay attention to the developments of nanotechnology and be involved, together with scientists, in the development process." During the last few years, the issue of NT has become increasingly topical, appearing on the agendas of some national parliaments.

56. In 2003, the US congress passed the *21st Century Nanotechnology Research and Development Act*, which President Bush signed into law on December 3, 2003. The bill was sponsored by Senators Ron Wyden (D-OR) and George Allen (R-VA) in the Senate, and Representative Sherwood Boehlert (R-N.Y.) in the House. The main purpose of this Act was to support America's efforts to remain the undisputed world leader in NT. This legislation institutionalised programs and activities supported by the National Nanotechnology Initiative. It authorized $3.7 billion over the years 2005-2008 for the creation of the National Nanotechnology Coordination Office and the funding of federal government nanotechnology programs. It also provided for a research program to identify the ethical, legal, environmental, and other societal concerns related to NT. Interestingly, the House version of this bill called for a feasibility study of the molecular manufacturing, including determining "the key scientific and technical barriers" and, if possible, estimated timeframe. However, the final edition of the Act referred to a more modest "molecular self-assembly" feasibility. In June 2004, the bipartisan and bicameral Congressional Nanotechnology Caucus was established to promote NT and to "educate policy makers about this emerging area". Senators George Allen (the founding Chair) and Ron Wayden, as well as Representatives Sherwood Boehlert and Bart Gordon, are the co-Chairs of the Caucus.

57. In 2004, the Science and Technology Committee of the House of Commons of the United Kingdom prepared a comprehensive report on NT, titled "Too Little too Late? Government Investment in Nanotechnology". The report concluded that British government had failed "to

maintain the UK's prominent position in the field". According to the report, "Government investment in nanotechnology is at present insufficient" and "poorly focussed". The Committee urged the executive to produce a strategy to "make the UK the major player in nanotechnology". In its response, the Government accepted part of Committee's conclusions and reiterated its commitment to support NT programmes.

58. The German parliament has also engaged in debate over NT. In 2004, Bundestag's Committee produced an extensive study on NT for Education, Research, and Assessment of the Consequences of Technology. One chapter of this report was dedicated to possible military uses of NT. The report concluded that, although grave security risks seem unlikely in the short-term future, intensified international cooperation in various NT initiatives—including armament control – would be wise. Furthermore, if the scientific invalidity of visions of self-replicating nanorobots cannot be proven, further preventative measures must be taken, such as a ban on the production of NT systems able to replicate themselves in the natural environment. A large group of German parliamentarians also prepared a motion calling on the executive to pay particular attention to the development of NT. Among other suggestions, the parliamentarians emphasized the importance of initiating "a discussion on issues of arms control in the field of the military uses of nanotechnology and investigating the benefits of strengthened international cooperation between various nanotechnology initiatives with reference to policies surrounding arms control." Finally, they noted that "the question of whether a possible misuse of nanotechnology could be averted through preventative arms control should be of particular relevance."

59. While the European Union is not falling far behind of the US in terms of NT funding, according to Ottilia Saxl, Chief Executive of the UK Institute of Nanotechnology, the effectiveness of European efforts is undermined by different cultures across Europe (some European nations are more reserved than others) and duplication. However, EU is taking steps in this area. In 2004, the Communication from the Commission "Towards European Strategy for Nanotechnology" emphasized a need for the Union to increase and to better-coordinate NT funding, and to assess potential societal and environmental consequences. NT is one of seven priorities of EU's "6th Framework Programme for Research and Technological Development", the Union's main instrument for funding research in Europe. This Framework covers the period 2002-2006. Out of a total budget of 17.5 billion Euro, 1.3 billion is allocated to NT. In March 2005, the EU also launched "Nanolog", a Commission-funded project designed to coordinate research on the social, ethical and legal implications of NT and produce guidance for stakeholders and developers. The European Parliament has yet to include NT in its agenda. So far, EP's interest was limited to some MEPs expressing their concerns about political implications of NT, and some seminars on NT-related issues being held at EP's premises.

D. SCIENTIFIC CONTRIBUTION

60. One of the key pre-conditions in designing a comprehensive worldwide mechanism to meet the challenges of NT will be a meaningful contribution from the scientific community. Before any major decisions on NT regulation are made on the political level, reliable and thorough scientific assessments of NT feasibility, risks, and opportunities are urgently needed. Indeed, while a number of studies have been produced in recent years, scientists have yet to reach a consensus in many areas, such as prospects of self-replication for nanorobots, toxicity of nanoparticles and the timeframe of future NT development. There is also a need for the broader involvement of scholars in discussion on possible military uses of NT and potential consequences on military strategy and international arms-control regimes.

61. In light of NT's enormous potential, society should remain well-informed about latest developments in this field. It is for this reason that transparency in NT research is crucial, as is cooperation and regular exchange of information between scientists worldwide. Developing

countries could also benefit from such transparency, thereby reducing the possibility of "nanodivide".

62. Dr. Altmann suggests that "the technologically leading nations should exercise unilateral and coordinated restraint with respect to military NT activities, in particular de-emphasising or avoiding those that could lead to defensive uses." Conversely, libertarian thinkers such as Dyson maintain that the world's scientific community is mature enough to responsibly and wisely guide the development of NT. Recalls the case of biological weapons, Dyson expressed confidence that scientists will refuse to contribute to production of apocalyptic weapons. The American biologists and Matthew Meselson in particular, managed to convince the Nixon administration that the biological weapons had posed enormous danger to the US security. As a result, in 1969, Nixon unilaterally declared that the United States was dismantling its biological weapons programme. Other countries followed the example, and consequently the BTWC was born in 1972.

VI. CONCLUSIONS

63. The military uses of nanotechnology cannot be considered independently of NT's other uses. Possible misuses both in military and civilian realms are related to the more general problem of the pace of human adaptation to new technologies. According to some assessments, NT revolution is comparable to industrial revolution of late Middle Ages, which posed an appreciable challenge for societies of that time. The NT revolution will be different, however, in that it will proceed much faster. According to Mihail Rico, nanotech advisor to the White House, "because of NT, we'll see more changes in the next 30 years than we saw in all of the last century."

64. Nanotechnology promises both great opportunities and risks. New technologies offer unique prospects of curing the world's age-old intrinsic defects and pushing globalisation to its extreme. At the same time, we must be aware of NT's potential to engender dangers never before encountered. What is most disquieting is the uncertainty of possible implications to the vulnerable domain of national security and defence. Very few publications and studies have been issued on this particular issue, and some of the assumptions and conclusions of those that have might still be speculative.

65. Nevertheless, your Rapporteur wishes to emphasize the importance of discussing and debating this issue now, when the international community and nation states are still in a position to shape a *preventive* mechanism capable of dealing properly with possible malevolent applications of NT in the field of national and international security. The Rapporteur strongly believes that the parliamentarians could and should contribute more extensively to such discussions.

66. Additional lengthy and scrupulous studies of military NT are urgently needed. The prospects of molecular NT should be assessed with particular attention, as this is the most controversial aspect of NT and would present extremely grave consequences if its feasibility is confirmed. The scientific research on NT should receive adequate funding. Ann Dawling, chair of the Royal Society and Royal Academy of Engineering's working group on NT, recently stated that, while the British Government seem to understand the importance of NT, it failed to actually increase funding for the research that is necessary before issuing appropriate regulations.

67. The governmental institutions should closely follow the latest information on NT development and be prepared to act promptly, should any adverse consequences be discovered. Ideally, governmental actions should be preventive rather than reactive.

68. Discussions should be encouraged on possible amendments of existing arms-control agreements, primarily with respect to BTWC and CWC. Verification mechanisms should be

reinforced and developed both for NT and by NT; that is, using the technological advances made in this field. If the progress of NT is as rapid as the enthusiasts expect, the international community might consider concluding a separate multilateral agreement designed specifically for this field.

69. In concluding, your Rapporteur wishes to urge his honourable colleagues to initiate or resume discussions on NT in the appropriate committees of their parliaments and exert their right of parliamentary oversight over the executive branch in order to ensure that the governmental institutions grant all due attention to this issue.

70. When it comes to making political decisions, policy makers should be impartial and weigh the arguments of both supporters and opponents of NT. While some enthusiasts tend to overemphasize the magnitude of NT, seeking additional funding, sceptics might be too cautious and thus obstruct the development of NT, regardless of its benefits to the society. The issue, therefore, is to be considered in balanced and cool-headed manner.