FONDATION pour la RECHERCHE STRATÉGIQUE

rapport final

Les impacts de la convergence technologique sur les accords de désarmement et de maîtrise des armements

ELISANDE NEXON – MGI PATRICE BINDER (2S)

Rapport n° 88bis/FRS/AKORDESARM
du 31 janvier 2014

Version anglaise

Marché n° 2012 1050146630 notifié le 8 octobre 2012
Par lettre n° 6662/DEF/SGA/SPAC/SDA/BPPE

FONDATION *pour la* RECHERCHE STRATÉGIQUE

WWW.FRSTRATEGIE.ORG 4 BIS RUE DES PÂTURES 75016 PARIS TÉL.01 43 13 77 77 FAX 01 43 13 77 78
SIRET 394 095 533 00052 TVA FR74 394 095 533 CODE APE 7220Z FONDATION RECONNUE D'UTILITÉ PUBLIQUE DÉCRET DU 26 FÉVRIER 1993

SOMMAIRE

The impact of technological convergence on disarmament and arms control agreements

"The views expressed are the views of the FRS, and in no way reflect either the position of the Delegation for Strategic Affairs or the positions of the Defence Ministry or the French Government".

According to a definition by the European Commission, converging technologies may be regarded as "enabling technologies and knowledge systems that enable each other in the pursuit of a common goal". Having regard more specifically to the convergence of life sciences, physical sciences and engineering, a report by the *Massachusetts Institute of Technology* (MIT) identifies this convergence phenomenon as the third revolution, after the rapid development of molecular and cellular biology and the rise of genomics.

Although the concept of convergence is widely adopted and quoted, there are divergences in terms of definition and scope, especially between the American and European approaches. With the publication of the "NBIC" report the Americans have put their stamp on a process focusing on improving human performance by the convergence of nanotechnologies, biotechnologies, information technologies and cognitive sciences. Thus it advocates "unifying science". Integration and synergy among these four major areas of emerging technology are described as opening up fresh prospects in terms of improving human physical and intellectual capacities, society, national productivity and the quality of life. Close on their heels, the European Union has also shown interest in technological convergence. In response to the NBIC report the European Union has set up a high-level expert group, "*Foresighting the New Technology Wave*". The importance of the military dimension and the focus on seeking to improve human performance are not given the same predominance in the European approach, developed in the Nordmann Report. The European concept, expressed by the acronym CTEKS ("Converging Technologies for the European Knowledge Society"), lays stress on needs and societal requirements.

Over and above conceptualisation controversies, converging technologies are a source of scientific and technical progress, offering a promise of rapid advances in technology; nonetheless, developments are associated with challenges in terms of safety and security, and therefore of governance. Accident, misuse and dual use are among the risks identified. This report deals more specifically with three major areas in which scientific and technological developments linked with convergence give rise to ethical, legal and societal questions, with a potential impact on arms control and defence: human health and improved human physical and cognitive performance, non-proliferation and chemical and biological disarmament and the development of autonomous weapon systems.

1 – Human health and improved physical and cognitive performance

Exploiting and combining new technologies offers the prospect of a revolution in terms of preserving and restoring capabilities, but also the prospect of improving human performance, for example, a promise of improved life expectancy as well as physical and/or cognitive capabilities. In the ultimate stage the goal is no longer solely to exploit these technologies by means of tools but to integrate them into the human body. Many solutions, some of which already exist but still have to be improved so that they can be put to practical use, are going to benefit *inter alia* from advances in miniaturisation and in the identification of the specific properties of components on the nanometric scale.

For example, those developments that are put to practical use may take the form of greater endurance, improved visual or auditive capabilities, shorter reaction times, better productivity, greater creativity or even improved resistance to stress. These various advances are indisputably of interest to the armed forces. They might have a direct effect on operational capability, with potential applications as diverse as:

- individual medical monitoring of combatants;
- assumption of medico-psychological control, in particular with the possibility of restoring a function after an attack on physical or even psychological integrity;
- optimisation of recruitment and training;
- improving the cognitive performance of operators and combatants;
- improving the physical performance of combatants;
- remote guidance of weapon systems such as robots or drones.

1.1 – Detection in the environment and personalised medical monitoring

Progress in system integration and miniaturisation, with recent advances in the field of micro- and nanotechnologies or information and communications technologies, reveals new prospects for sensors, devices that will convert an observed physical magnitude into a usable analytical signal. The development of microelectromechanical and nanoelectromechanical systems (MEMS and NEMS) has made significant advances possible[1]. These must then be linked with signal-processing techniques, but the possibilities of data transmission must also be taken into account according to the function required (warning the user and/or a person carrying out remote monitoring), and possibly an energy source.

From the viewpoint of use by the armed forces, several functions for these devices may be considered, selecting appropriate sensors:

Personnel medical and physiological monitoring. Sensors are used to monitor vital signs and other physiological parameters (mechanical, thermal, biological, chemical, optical,

[1] MEMS can be defined as microscopic systems linking mechanical, optical, electromagnetic, thermal and fluid elements and electronics on semiconductor substrates.

acoustic or magnetic)[2]. However, there are differences in maturity among the various existing devices.

Moreover, work is in progress to develop biochemical sensors that can be used to detect specific ions or markers that may, for example, represent effort or a state of stress. In the case of non-invasive sensors, sweat is the preferred bodily fluid[3]. This involves identifying the relevant ions or markers and then being able to establish correlations between analysis results and physiological condition so as to be able to make practical use of these researches, for example for personalised medical or physiological monitoring.

A patient's emotional, sensory and cognitive reactivity can also be studied by monitoring autonomic nervous system (ANS) activity, with measurement of resistance, skin temperature and heart rate using non-invasive sensors linked to a system attached to the wrist. So perfecting these devices involves miniaturisation with component integration and low energy consumption, in order to have enough operational range available[4].

- ⇨ Medical monitoring of personnel who have been injured or have contracted a disease, sensors helping *inter alia* diagnosis and making a prognosis. Medical monitoring is already used quite extensively in medicine, particularly in emergencies. If technical improvements are to be made (in particular system miniaturisation) the principles characteristic of this application are unlikely to change;
- ⇨ Physiological monitoring of personnel in the course of an operation gives rise to more problems. Using a sensor is based on a special sequence which in outline takes the form of a linear sequence of stages: 1) Person, 2) Sensor, 3) Measurement, 4) Transmission, and lastly 5) Interpretation.

In-depth research on human physiology (e.g. work on sweat) is required beforehand, in order to decide which are the most relevant parameters to be measured and possibly to identify others. Studies are also essential in order to define warning levels, the thresholds at which doctors consider that a situation is becoming abnormal. So work on human physiology is also indispensable so that the last stage, signal interpretation, is possible. But as yet there is insufficient knowledge in this area.

So the risk is that sensors will be developed that cannot measure the most relevant parameters, or that collect data that we do not know how to exploit. So perfecting physiological monitoring sensors calls for cooperation among several disciplines (medicine – in particular physiology – biology, electronics, etc.).

- ⇨ *Selective or non-selective detection of biological agents or toxic substances present in the environment that may lead to potentially serious damage to health*. The advances relate mainly to miniaturisation, particularly with the use of microelectromechanical systems (MEMS) and nanotechnologies. The goal is to be able to develop portable, selective and sensitive sensors and at low cost

[2] Mozafari R., ed., « Nanomaterials and nanosystems for biomedical applications », Dordrecht, The Netherlands: Springer. 2007.

[3] There is also some work on detection of biomarkers in the breath.

[4] Massot B., Gehin C., Nocua R., Dittmar A., McAdams E., « Centrale de mesure ambulatoire biomédicale sur PSoC », *IRBM*, 2009.

and therefore suitable for manufacture. Speed of detection is also still a decisive factor.

The technology is more advanced in the case of chemical sensors that for biological sensors. In particular current R&D projects include work on nanotubes or carbon for gas sensors and biocaptors, or on silicon nanowires for biosensors[5].

In the specific context of arms control, these sensors may have previously been regarded as technical resources that might be used within the framework of existing instruments, particularly the Convention on the Prohibition of Chemical and Biological Weapons or in the event of an investigation in cases of alleged use of such weapons.

Where there is a risk of exposure to chemical or biological agents, sensors that can be used to detect contamination in the environment – and therefore used as a dosimeter in the event of exposure to ionising radiation – might be helpful in protecting inspectors by directly warning the person exposed, enabling him to move to a safe area and deploy suitable countermeasures (in this case a warning sensor), or possibly by giving medical personnel information on the nature of the exposure. Sensors that can be used for personal physiological monitoring might also be used in situations requiring physical constraint, for example wearing CBRN protective clothing.

1.2 – Improvement of human performance

This is the approach that underlies the American view, as developed in the report on *Converging Technologies for Improving Human Performance*[6]. In the case of the defence sector there seem to be many direct or indirect applications exploiting various types of technological convergence. Consideration of the ethical and legal aspects accompanies the development of these new technologies and potential applications.

1.2.1 – Enhancement of physical performance

As regards physical performance, resorting to external devices and tools designed by virtue of technological convergence may make it possible to improve or restore certain capabilities. This applies in particular to prostheses or exoskeletons.

The first European exoskeleton, *Hercule*, was developed by the RB3D Company (PME) (which also proposes solutions to combat muscular and skeletal disorders) in partnership with CEA-List and ESME Sudria with backing from the Ministry of Defence through the RAPID mechanism, the Directorate General for Armaments (DGA) dual innovation support system. Its characteristics are a wide operational range, fluidity of movement and the absence of sensors; the latter facilitates fitting to the user. Latest-generation motors guarantee excellent performance. It weighs about twenty kilos and makes it possible to carry a 100-kg load at a speed of 4 $km.h^{-1}$. Marketing for civilian applications is scheduled for 2015.

Other prototypes have been developed, notably in Japan and the United States. Thus the Defense Advanced Research Projects Agency (DARPA) *Warrior Web Project* is

[5] Bondavalli P., Legagneux P., Pribat D., « Carbon nanotubes based transistors as gas sensors: State of the art and critical review », *Sensors and Actuators B*. 2009;140:304-318. Use of such weapons.

[6] Roco M., Bainbridge W., « Converging technologies for improving human performance: Integrating from the nanoscale », *Journal of Nanoparticles Research*, 2002;4:281-295.

dedicated to designing flexible armour that should reduce fatigue and prevent effort-linked injuries, while improving the combatant's performance. According to the technical specifications, this armour should weigh less than ten kilos.

Thus for example the motorised exoskeleton, which has potential civilian and military applications, is designed to be able to handle heavy loads. In the armed forces, exoskeletons might be particularly useful to infantrymen and gunners, called upon to shift materiel or ammunition. They will make it possible to improve locomotor and operational capabilities. In addition to these external aids, consideration should also be given to invasive solutions, for example implants to improve vision or hearing. However, this approach raises ethical questions precisely because of its invasive nature. It involves a surgical procedure, with its attendant risks.

1.2.2 – Optimisation of cognitive performance and neurosciences

Improving cognitive performance involves seeking to improve certain cognitive functions such as perception, memory, alertness, concentration or decision-making in healthy individuals, i.e. apart from any medical necessity. It is still necessary to improve knowledge regarding cerebral development and function, in order to press forward with research on neurological ailments.

A.– Improving knowledge about the brain

Rapid developments in the neurosciences based on an interdisciplinary approach has led to substantial advances in knowledge about the human brain and convergences with nano-biotechnologies, engineering sciences and computer science have made it possible to develop new tools and methods for operating at the cerebral level.

The development of *in vitro* models is a part of the approaches leading to a better grasp of the complexity of the human brain, which is not possible with the animal models currently in use. An Austrian Academy of Sciences Institute of Molecular Biotechnology (IMBA) team has been successful in obtaining cerebral organoids from pluripotent stem cells in a three-dimensional culture system[7]. Even though they are called "mini-brains" and at present can survive for up to ten months in a bioreactor, in fact these 3 to 4 mm structures correspond to masses of human cerebral tissue and have no blood circulation, which explains why they cannot grow further. This advance has made it possible to simulate the development of microcephaly[8] and to identify its origin. Moreover, in the long term these "mini-brains" may be of interest to the pharmaceutical industry for testing therapeutic strategies directed against cerebral malformations or neurone disorders, and to the chemical industry, by making it possible to study the effects of chemical products on cerebral development.

In another approach, a multidisciplinary French team has designed silicon microchips withmicro/nanometric modifications at surface level. A study based on an anaesthetised monkey has shown that they make it possible to obtain a molecular and cellular imprint at the level of the brain area with which they are interacting. Thus this tool provides the

---

[7] Lancaster M., Renner M., Martin C-A., Wenzel D., Bicknell L., Hurles M., Homfray T., Penninger J., Jackson A., Knoblich J., « Cerebral organoids model human brain development and microcephaly », *Nature*, 28 août 2013 (on line).

[8] Microcephaly can be defined as abnormal smallness of the head, generally associated with mental retardation.

potential ability for molecular explorations *in vivo* at the cerebral level on animal models[9].

B.– Ways of enhancing cognitive performance

The ways and strategies that can be used to enhance cognitive capabilities are extremely varied, and technological convergence has helped to extend the range of possibilities. These include, for example, education and mental training, certain pharmacological substances or even brain-machine interfaces.

➡ Using substances having a pharmacological action

Neuropharmacology may be defined as the study of the metabolism and action of substances influencing the working of the nervous system and consequently the brain, the organ that regulates the vital functions as a whole. Neurocognitive functions such as memory and learning, creativity, confidence, empathy and decision-making, alertness and the control of impulses, humour and self-esteem, or even waking and sleeping, may be modified by the use of phamacological substances that act at the level of neurotransmission. At present little is known about their effects on persons in good health[10].

Two substances may be mentioned as examples of medicines that are used as drugs and may make it possible to improve cognitive performance. Ritalin, normally prescribed in cases of attention deficit hyperactivity disorder, is used for its effects on waking, concentration and memory. Modafinil, indication of which is restricted to narcolepsy from now on, is used to restore and/or improve wakefulness and diurnal alertness, depending on the dose[11]. They make it possible to maintain alertness and performance in a sleep-deprivation context, e.g. during military operations[12]. Otherwise two transmitters (known as orexins or hypocretins) identified during research on narcolepsy are also proving interesting[13].

While the possibility of optimising cognitive performance by administering substances is recognised and dealt with in scientific publications, this practice gives rise to a certain amount of distrust and is even seen as negative, depending on the context. In fact it may be regarded as dangerous and as a means of cheating, thought of as doping. The use by students or executives of certain stimulants such as ritalin[14] to increase attention and alertness in order to improve efficiency is an example of the misuse of these substances.

---

[9] Zaccaria A., Bouamrani A., Selek L., El Atifi M., Hesse A-M., Juhem A., « A micro-silicon chip in vivo cerebral imprint in monkey », *ACS Chem Neurosci*, 2013;4(3):385-392.

[10] Hildt E., Franke A (Eds). « Cognitive enhancement – An interdisciplinary perspective », Springer, 2013.

[11] ANSM (ex-AFSSAPS). *Modafinil : restriction d'indication et nouvelles recommandations (communiqué)*. 26 July 2010. Following reconsideration of safety and efficacity data, the European Medicines Agency has recommended restricting indications to narcolepsy because the risk-benefit ratio for other indications is unfavourable. In addition, an assessment of the risk of misuse is requested. The United Kingdom is behind the request for reconsideration, following reports of undesirable psychiatric and cutaneous effects.

[12] Beaumont M. Aide pharmacologique au maintien de la vigilance et de la performance en opération continue : intérêt d'une combinaison hypnotique / psychostimulant. In *Stratégies pour le maintien de la préparation au combat lors de déploiements prolongés – Une approche systèmes humains, 2005,* pp. 30-1 – 30-16.

[13] Ollat H., « Narcolepsie et hypocrétines / orexines », *Neuropsychiatrie : Tendances et débats*, 2002;17:31-38.

[14] Wilens T., Adler L., Adams J., Sgambati S., Rotrosen J., Sawtelle R. et al. « Misuse and diversion of stimulants prescribed for ADHD: a systematic review of the literature », *J Am Acad Child Adolesc Psychiatry*, 2008 Jan;47(1):21-31.

Some of these may prove to be illegal or reserved for specific therapeutic use, so that they are available on prescription only. Dispensing them is controlled because of potential side-effects and the risk of addiction, so they are far from being harmless and without risk to health[15].

The possibility of using substances to optimise healthy persons' potential is the subject of debate, given its attendant ethical dimension. Some take the view that the negative aspects of their use should be set aside and that the chance of studying the prospects opening up in this area should not be missed, in view of the potential benefits in certain fields, particularly in wakefulness and alertness. But we should not lose sight of the risks, but consider instead how society can support and manage these developments, which involves specific biomedical research, and if necessary amending the regulatory framework[16]. In fact there are still insufficient data to assess whether the risk-benefit ratio is favourable in the event of use for optimisation. The efficacity of some of these substances might be overestimated, and physical and psychological side-effects might be badly identified. Thus the studies show that, paradoxically, the taking of stimulants by persons suffering from attention deficit hyperactivity disorder produces no improvement in academic performance over the long term, contrary to what might be expected. Thus researchers have noticed that although these stimulants make it possible to reduce reactions generated by frustration, improve error detection capability and stimulate the capability to make efforts, they do tend to increase high-risk behaviour and susceptibility to environment-linked distractions. So there are many influences acting on behaviour[17]. In addition it seems that the importance of inter- and intra-individual variability should be taken into account. Thus certain groups might benefit from using a substance whereas it might have but little effect on other individuals[18].

- Brain-machine interface (BMI)

The rise in neurosciences based on an interdisciplinary approach has led to considerable progress in knowledge of the human brain, while for a long time very little had been known about how it functions. The convergence of nano-biotechnologies and engineering sciences has made advances possible, particular with the development by miniaturisation of dedicated tools for brain operations or even using the specific properties of nanometric-scale components for coating implantable devices. Allied with computer science, this knowledge also makes it possible to develop location strategies.

Research involving clinical tests is in progress to perfect brain-machine interfaces (BMI), which may be defined as systems directly linking brain and computer making it possible to communicate with the environment without recourse to the peripheral nervous system and the muscles. Among potential BMI applications, the ones in the area of health are those where communication is most important. In particular these interfaces provide a means of communication for patients with amyotrophic lateral sclerosis (ALS, at the origin of progressive paralysis and amyotrophy) and those

---

[15] Rosenfield D., Hébert P., Stanbrook M. et al., « Il est temps de lutter contre l'abus de stimulants sur nos campus », *CMAJ*, 2011;183(12):1388-1389.

[16] Greely H., Campbell P., Sahakian B., Harris J., Kessler R., « Towards responsible use of cognitive-enhancing drugs by the healthy (Opinion) », *Nature*, 7 décembre 2008.

[17] Advokat C., Sheithauer M., « Attention-deficit hyperactivity disorder (ADHD) stimulant medications as cognitive enhancers », *Front Neurosci*, 2013;7:82.

[18] Husain M., « Cognitive enhancement by drugs in health and disease », Trends Cogn Sci, 2011;15(1):28-36.

suffering from certain bone marrow lesions or cerebral vascular failures involving complete paralysis. Coupled with an exoskeleton, they will allow paralysed patients to recover a measure of mobility.

Recent scientific publications show that the advances are substantial, but technological limits still remain. The outstanding issues are focused on perfecting neuron signal acquisition systems and data processing, involving monitoring the greatest possible number of neuron signals as well as the capacity to manage substantial data flows and carry out real-time analysis. Limiting background noise is also essential. Methods may be non-invasive, partially invasive or invasive. This implies the development of high-performance biocompatible sensors tolerated by cerebral tissue and complex computing solutions such as signal-processing algorithms. From a practical point of view the system must be able to function outside the laboratory, in the planned conditions of use, and so must resist movement. Apart from the technological aspects there must be a training process for the interface user, who must be able to modulate the brain signals in order to improve the performance of the device.

At the national level it is interesting to look at the results submitted by French teams. These illustrate the dynamism of the research.

For example Clinatec®, a biomedical research laboratory developed by the CEA, Grenoble University Hospital and Joseph Fourier University in partnership with Inserm, is in the forefront of applied nanotechnologies in the area of health. In particular the research is directed to developing diagnostic tools, devices for localised administration of active principles, medical devices for neurostimulation or even neuroprostheses for functional replacement. The last three lines of research are based on the development of minimally invasive implantable medical devices. Their aims are to make it possible to take on patients earlier and to perform more effective targeted operations less traumatising for the body, opening the way to preventive medicine taking the biological characteristics of individuals into account.

The Neurocom partnership project has made it possible to perfect a high-density multielectrode system with integration on silicon which is now marketed, making it possible to record and stimulate large neuron networks *in vitro* and *in vivo* on a microelectrode matrix[19]. This integration, allowing simultaneous monitoring of activity in many neurons, has been described as a stage in the process of developing an implantable device that can be used as part of studies on brain-machine interfaces and neural prostheses[20]. This system has been completely reshaped as part of the RETINE project, with the development of a new system called NeuroPXI offering 256 channels for real-time recording, processing and stimulation[21].

More specifically, in the BMI area work by Clinatec® on neuroprostheses for functional replacement aims *inter alia* to compensate for motor, visual or auditory deficiencies. As part of the brain-machine interface project the objective is to implant a microchip on the

---

[19] *CLINATEC : Les micro-nanotechnologies au service de la santé* (Dossier de presse). 19 juin 2009.

[20] Charvet G., Billoint O., Gharbi S., Heuschkel M., Georges C., Kaufmann T. et al., « A modular 256-channel micro electrode array platform for in vitro and in vivo neural stimulation and recording: BioMEA™ », *32nd Annual International Conference of the IEEE EMBS.,* Buenos Aires, 2010.

[21] Bonnet S., Bêche J-F., Gharbi S., Abdoun O., Bocquelet F., Joucla S. et al., « NeuroPXI: A real-time multi-electrode array system for recording, processing and stimulation of neural networks and the control of high-resolution neural implants for rehabilitation », *IRBM*, 2012;33:55-60.

brain surface in persons with severe motor disorders; this should make it possible to transform signals into movement by a robotised limb on the basis of cortical electric recording. The first tests on a human being have been authorised by the French National Agency for Medicine and Health Product Safety (ANSM), since tests on the monkey and the pig have not revealed any side-effects.

It must be possible to demonstrate that these devices are harmless and effective. Pre-clinical tests – involving experiments on animals, because it is still not possible to replace them systematically by simulation or by experiments *in vitro* – and clinical trials, essential stages in biomedical research, must conform to the regulatory framework currently in force. Thus in France the Committee for the Protection of Persons (CPP)[22] must give its approval and the ANSM must grant authorisation before the start of a clinical trial, i.e. on man.

Although the research projects are focused mainly on optimising stimulation protocols to improve certain cognitive capabilities and on physical side-effects, the risk that this improvement might be to the detriment of other cognitive functions must also be taken into account[23].

C.– Defence applications

Developments in the field of neurosciences are of interest from a military viewpoint, as shown, for example, by two American reports published in 2008 and 2009: *Emerging cognitive neuroscience and related technologies*[24] and *Opportunities in neuroscience for future army applications*[25]. A 2012 report by the Royal Society on neuroscience, conflict and security identifies a certain number of techniques and developments that might be exploited in the field of defence, particularly in the context of recruitment, training, operational capacity and "repair"[26]:

- ⇨ Neuroimaging techniques may give pointers on neural flexibility and risk-taking behaviour (recruitment). They have also made it possible to identify neural markers associated with visual perception under the awareness threshold (target detection);
- ⇨ Brain stimulation techniques (training);
- ⇨ Neuropharmacological agents helping to improve cognitive functions and limit the effects of sleep deprivation (operational capacity), but also offering new prospects for treating post-traumatic stress;

---

[22] According to Article L.1123-6 of the Public Health Code, introduced by the Law of 9 August 2004: "*Before conducting biomedical research on the human being, the organiser shall submit the project for approval to one of the committees for the protection of persons for the place where the investigator, or if need be the coordinating investigator, conducts his activities*".

According to Article L.1123-12: "*The competent authority shall be the National Agency for Medicine and Health Product Safety. When a collection of biological samples is made solely for the requirements of biomedical research, it shall be declared to the competent authority*".

[23] Luculano T., Cohen Kadosh R., « The mental cost of cogntive enhancement », *The Journal of Neuroscience*, 2013;33(10):4482-4486.

[24] National Research Council. Emerging cognitive neuroscience and related technologies. Washington, DC: National Academies Press. 2008.

[25] National Research Council. *Opportunities in neuroscience for future army applications.* Washington, DC: National Academies Press. 2009.

[26] The Royal Society, « Brain Waves Module 3: Neuroscience, Conflict and Security », 2012.

- ⇨ Neural interface systems making connection between a human being's nervous system and a system (remote control, but also "repair" after wounds);
- ⇨ Technologies for improving neural performance.

Moreover, projects developed within the DARPA (*Defense Sciences Office*) framework provide a good illustration of the full potential of these new technologies. In April 2013 President Obama announced the launch of a research programme intended to revolutionise knowledge of the human brain. The Director of DARPA summarised the philosophy and aims of this initiative as follows:

« *The President's initiative reinforces the significance of understanding how the brain records, processes, uses, stores and retrieves vast quantities of information* »[27].

In fact DARPA is going to invest about 50 million dollars in 2014 in research on brain function and in perfecting new applications based on the result of this work. Two main lines of research have been identified: on the one hand the development of new tools to measure and analyse electrical signals and molecular processes at the cerebral level, and on the other exploration and simulation of brain functions. Advances in this field will make it possible to increase knowledge regarding cerebral lesions and repair mechanisms, as well developing new diagnostic tools, therapeutic strategies and devices intended for use in the event of traumatic injury. They may also be helpful in designing new processors. Related societal issues will also be addressed.

Among the various lines of current research funded by DARPA the following, based on multidisciplinary approaches, will contribute more specifically to progress in the neuroscience field or help to exploit knowledge on the functioning of the human brain, with actual applications for the armed forces:

- ⇨ **SyNAPSE – Systems of Neuromorphic Adaptative Plastic Scalable Electronics**. The aim of this project is to design a processor reproducing the way in which the human brain processes information. As part of this, IBM among others has developed neuron chips with sensors capable of simulating certain human brain processes, as well as a programming model.
- ⇨ **REMIND – Restorative Encoding Memory Integration Neural Device**. This involves finding the way in which the short-term memory is encoded in order to be able to restore memory subsequently using devices that make it possible to bypass damaged regions of the brain. A biomimetic hippocampus model might play the part of a neural prosthesis.
- ⇨ **Enabling Stress Resistance.** Development of a suitable animal model should make it possible to study the effect of multiple stress factors on the brain, using new technologies and advances in the fields of molecular neurobiology, neuro-imaging and molecular modelling. The aim of this approach is to develop cognitive, behavioural and pharmacological means of preventing or limiting the effects of stress.
- ⇨ **Revolutionising Prosthetic**. This programme, launched in 2006, has led to the design of two modular robotic arm prosthesis prototypes, perfecting prostheses for the upper limbs being regarded at the outset as more complex from a

[27] DARPA, « *Better understanding of human brain support national security* », (Press release) 2 April 2013.

medical and technical viewpoint. In this context researchers have obtained promising results regarding control of such a system by way of a neural interface[28],[29].

- **Narrative networks**. This programme relates to study of the effect of narratives in cognitive and behavioural processes, for example by seeking to determine their possible role in post-traumatic stress disorder, but also how they might contribute to its treatment. The lines of research include analysis of the neurobiological impact of these narratives on hormones and neurotransmitters, interaction between emotion and cognition and the reward circuit.

- **DCAPS – Detection & Computational Analysis of Psychological Signals Information.** This involves the development of new analytical tools that can be used to assess the psychological state of military personnel in a context characterised by a high incidence of post-traumatic stress disorder in veterans returning from Iraq and Afghanistan.

DARPA programmes with aim of contributing to human performance optimisation also include:

- **Biochronicity**. This relates to the role of time in various biological functions, since almost all of them are subject to biological clocks. A better knowledge of these rhythms might find expression in terms of combatant performance, but also in terms of treatments and surgical operations, or even in understanding certain pathologies.

Thoughts in this area are not limited to the Anglo-Saxons; there was a report by the Conseil Général de l'Armement in 2012 on this theme[30]. In the main it follows three lines:

- The contribution by biomedical neuroscience intended for the care of military casualties and victims;

- Technologies and resources maintaining performance by the military and affecting their relationship with systems;

- Improving strategies for selection, in-service instruction and training of the military.

In addition to scientific and technological considerations, the report stresses the importance of keeping within ethical limits, represented by three principles: the **principle of reversibility, the free arbiter principle and the principle of respectability and respect for the lives of others.** As regards reversibility, over and above the consequences for the person himself, consideration must be given to the place

---

[28] Hochberg L., Bacher D., Jarosiewicz B., Masse N., Simeral J., Vogel J. et al., « Reach and grasp by people with tetraplegia using a neurally controlled robotic arm », *Nature,* 2012;485(7398):372-375.

[29] Collinger J., Wodlinger B., Downey J., Wang W., Tyler-Kabara E., Weber D. et al., « High-performance neuroprosthetic control by an individual with tetraplegia », *Lancet*, 2013;381(9866):557–564.

[30] Binder P., « Évolution des neurosciences : conséquences pour la défense », 2012.

of that person (for example, a serviceman returning to civilian life after a foreign operation) in civil society and the issue of acceptability by others[31].

D.– Issues and governance

The issues that have to be studied are of various kinds – ethical, legal, societal, even philosophical – and will be linked to the stages of development in technology. Problems within the province of arms control may be raised, in the same way as questions relating to human rights and affecting the integrity and inviolability of the human body. When research is not concerned solely with improving knowledge but is seeking to develop applications intended to improve human performance – as compared with preserving or restoring functions – a line is crossed and the question may arise differently, from an ethical viewpoint, for the researchers and health professionals involved. The questions that arise when the point at issue is study of the feasibility of integrating technologies into the human body, in particular resorting to invasive or partly invasive solutions, are not appropriate for this type of technology, but fall within the province of biomedical research.

Beyond the R&D phase, how technological solutions will be used, by whom and for what purpose, must be considered. Their intrinsic characteristics and the risks to which a person might be exposed, for example if the use is for a prescribed time or involves an invasive device calling for surgery, are quite obviously going to affect risk-benefit ratio assessment. In addition, the question must be put in terms of acceptability by those whose performance might be improved, but also by the family circle and the population in general.

The neurosciences are a source of particular concern. In France a report by the Parliamentary Office for the `evaluation of Scientific and Technological Choices (OPECST) stresses the extraordinary advances that have been made in this area and brings out the issues, while emphasising that this progress gives rise to ethical, philosophical, legal and social tensions. The National Consultative Ethics Committee for Health and Life Sciences has also given an opinion on ethical issues in the context of resorting to biomedical techniques with a view to "neuro-improvement" in a person who is not ill. It identifies two major questions, one relating to health, research, medicine and social protection, the other to the person and life in society, concluding that ethical monitoring was vital.

Although research projects in this field mainly focus on optimising stimulation protocols to improve certain cognitive capabilities and on their physical side-effects, allowance must also be made for the risk that this improvement may be to the detriment of other cognitive functions. In addition, the prospects of using cerebral implants for non-medical purposes such as location, surveillance or even the possibility of influencing behaviour or decision-making give rise to the fear of abuse for malicious purposes. These potential uses make it essential to consider the consequences in terms of human dignity and respect for private life, and also the risks of attacks on personal identity and autonomy.

The dual nature of these researches and technologies, with civil as well as military applications, must be taken into account and consideration given to what their impact

---

[31] Allenby B., « Are new technologies undermining the laws of war? », *Bulletin of the Atomic Scientists*, 2014;70(1): 21-31.

might be from an operational viewpoint, but also in terms of arms control. This analysis will depend on the techniques considered themselves, as well as the applications contemplated. The whole point is to assess whether and particularly how to manage the development of these technologies but without curbing innovation and research.

Some advances should have been considered already in the context of existing international instruments, while others give rise to fresh questioning and make it essential to think about new methods of governance. Thus the potential implications of developments in the field of neurosciences must be taken into account in the context of the Chemical Weapons Convention (CWC), as well as the Biological Weapons Convention (BWC). While it is possible to improve cognitive performance it is equally possible to seek the contrary, i.e. deterioration in the enemy's performance. However, using biochemical substances is not the only way of inducing disturbances in the central nervous system or the peripheral nervous system. For example, at present developments in the field of directed energy weapons are not dealt with.

However, even before considering existing international instruments or what should be negotiated, we should begin by stressing the importance of issues of responsibility of scientists and of governance applicable to scientific research, even if these subjects do not relate specifically to the areas characterised by converging technologies. It should be noted in this connection that the debates on nanotechnologies or synthetic biology show that the scientific community is aware of the issues and the risks of abuse.

1.3 – Recommendations

Recommendation 1: Given the developments emerging, according to current research and thinking, especially in the United States, it seems important to participate in thinking on the issue of improving human performance, the more so because France has research capabilities in this area. This research holds out fantastic prospects, but the limits and the risks of abuse must also be considered.

The Academy of Sciences might be given the responsibility of organising this process, which should involve various actors: scientists in various fields affected by the developments (including pharmacologists, toxicologists, biochemists, engineers, etc.), doctors (including neurologists, psychiatrists, neurosurgeons, etc.), pharmacists, representatives of the ministries concerned (research, health, defence, industry, etc.), representatives of the agencies involved (French National Agency for the Safety of Medicines and Health Products, the Biomedicine Agency, etc.), lawyers, specialists in ethics (including the National Ethics Consultative Council, NECC), representatives of civil society (including the ICRC, etc.), philosophers, etc.

A number of issues, *inter alia*, are worth considering:

The state of thinking and programmes in the United States and at the European level: what are the differences and convergences?

On the basis of risk-benefit analysis, what technological applications and solutions can be implemented in the long term?

- ⇨ In the present state of knowledge, where can the limit between what is acceptable or not, on the basis of ethical and professional medical considerations?

- ⇨ Might certain applications give rise to a problem from the point of view of international humanitarian law, and to what extent?
- ⇨ Who might benefit from these improvements? Should access to these technologies be limited once they have been developed?
- ⇨ What are the lines of research that should be supported as a priority at national level?

A seminar focusing on the issue of improving human performance might be organised and the results of its thinking could be published by the Academy of Sciences in the form of a report.

2 – Non-proliferation and chemical and biological disarmament

Emerging technologies and convergence phenomena may have an impact in terms of duality, with the potential development of dual-use goods. When considering military use, or even abuse by non-State actors, of scientific and technological convergence, particularly of chemistry and biology, their impact on disarmament and arms control instruments should be assessed periodically. In fact they may weaken them or even render them obsolete, with improvements to existing weapons or the development of new weapons categories. Advances relating to converging technologies may also have an effect on export control systems (for example, informal groups or community systems) and on national control machinery involving, for example, the necessity for reassessing and if need be adapting the lists for control of exports of dual-use goods and technologies.

These scientific and technical advances may also have beneficial applications, contributing to the implementation of certain Chemical Weapons Convention (CWC) provisions, including provisions in the annex on verification, and the Biological and Toxic Weapons Convention (BTWC), or even the United Nations Secretary-General's mechanism for investigation of alleged use of chemical and biological weapons. These developments may make it possible to improve methods of detecting and identifying chemical or biological agents, medical diagnosis and countermeasures, individual protective equipment, or even methods of decontamination.

In addition, advances in converging technologies may also have an effect on export control systems (for example, informal groups or community systems) and on national control machinery[32]. Issues within the province of human rights and dealing with the integrity and inviolability of the human body also arise, for example with potential abuses in the neuroscience field.

2.1 – Taking scientific and technological developments into account in the BTWC context

2.1.1 – Articles in the Convention which may be affected by scientific and technological developments

The concept of scientific progress is implicit in Article I. Nevertheless the States Parties have felt the need to define the scope of the Convention on the basis of state of the art. At each Review Conference they have reaffirmed that scientific and technological developments were covered by Article I of the Convention:

Article I: *« Each State Party to this Convention undertakes never in any circumstance to develop, produce, stockpile or otherwise acquire or retain:*

1) Microbial or other biological agents, or toxins whatever their origin or method of production, of types and in quantities that have no justification for prophylactic, protective or other peaceful purposes;

[32] An international perspective on advancing technologies and strategies for managing dual-use risks: Report of a workshop, 2005 – http://www.nap.edu/openbook.php?record_id=11301&page=R1

2) Weapons, equipment or means of delivery designed to use such agents or toxins for hostile purposes or in armed conflict".

As from the second Conference[33], the paragraph in the final document dealing with biological agents and toxins states that these may have been "naturally or artificially created or altered".

The wording of the paragraph on scientific and technological developments has varied in the course of the Review Conferences. The paragraph inserted in the final document for the second and third Review Conferences adds *"inter alia, in the fields of microbiology, genetic engineering and biotechnology"*. The importance of the "*inter alia*" should be stressed. The final document for the fourth Review Conference adds molecular biology and any applications resulting from genome studies. The final document for the sixth Review Conference indicates a change, because the wording, adopted again in the declaration for the latest Conference, is intentionally less precise and therefore wider: *"all scientific and technological developments in the life sciences and in other fields of science relevant to the Convention"*.

So the principal issues linked to scientific and technical advances have been identified as from the first Review Conference. However, this reaffirmation seems to have been insufficient. Over and above the reaffirmation of the scope of Article I and of the Convention more generally, it is advisable to examine what the impacts of these developments are on the other provisions of the Convention, which makes it essential to have suitable machinery for this purpose, making it possible to adopt practical and pragmatic measures later if need be.

So it seems important also to consider the consequences with respect to Article III, which deals with the issue of technology and information transfers that may contribute to activities prohibited by Article I, and similarly with respet to Article IV on national implementation. Export controls and national regulations help to reduce the risks connected with dual-use goods and technologies, so the lists and measures must be reassessed periodically. It is also important to continue to publish and improve methods of assessment and risk management connected with dual-use goods and technologies. So training the various actors involved (for example, laboratory staff and customs officers) and raising their awareness are essential to effective implementation.

Moreover, some technologies may have beneficial applications. They may therefore be turned to good account in the context of Article VII on assistance to a State Party in the event of exposure to danger, or in the context of the cooperation provided for by Article X. Promoting international cooperation may be helpful in perfecting means of detection, identification, diagnosis, protection and treatment.

2.1.2 – *Machinery for assessing scientific and technological developments and their effect on the Convention*

In a message read at the conference of States Parties in December 2010 the United Nations Secretary-General stressed "the pressing need for a structured and regular means of monitoring developments and assessing their implications". Taking account of of scientific and technical advances in the life sciences that might be of significant importance to the Convention is among the concerns increasingly expressed.

[33] The final declaration after the fifth Review Conference is an exception.

Although these problems have been regularly tackled at successive Review Conferences, meetings of experts or annual meetings of States Parties, the issue of the adequacy of scrutiny in the context of the Convention still remains open. Over and above acknowledging its importance in a context in which life sciences are developing much more rapidly than the Convention, the real need is to consider how to meet this challenge effectively and in practice. Are existing procedures sufficient and do they make it possible to face present and future issues?

The first Review Conference, held in Geneva in 1980, made it possible to respond to the requirement set by the Article, and the matter was also considered during the next six Review Conferences. Although taking scientific and technical developments into account is provided for as part of the review of the Convention according to the text of Article XII, nonetheless the procedures for assessing this impact are not specified: who is to carry out this assessment? What are the criteria? How frequently? The procedure has evolved from Review Conference to Review Conference.

So the examination procedures have been defined by Preparatory Committees, with a few developments from Review Conference to Review Conference. For the first three Review Conferences the Preparatory Committee asked depositary States to forward information on scientific and technical developments affecting the Convention. As from the fourth Review Conference all States Parties, including the depositary States, are asked to send information. By the sixth Review Conference the machinery had evolved, because the Conference Secretariat prepared an information document. Lastly the ISU set up by the previous Conference was charged with drafting this document for the seventh Review Conference. Whatever the process adopted, all States Parties that so wish have the opportunity to submit information documents. Before each Conference State Parties have submitted preparatory documents, but the tempo of these Conferences has not left time for these to be analysed in any great depth, for which once more some of those attending the last Review Conference have expressed regret.

The rate of process in the life sciences makes it essential to consider how frequently such an examination should be carried out. In addition, the time spent on discussing this topic at Review Conferences is inevitably limited. Many States Parties have emphasised the necessity for reviewing this examination process and for devising a process appropriate to the issues (see official statements and proposals submitted by States Parties during the seventh Review Conference, and comments by actors from civil society).

So this consensus made it possible to expect progress on this situation by the Seventh Review Conference. In the Final Document the Conference decided in the end that a permanent item on the agenda dealing with the examination of scientific and technical innovations would be introduced into the inter-sessions progrmme for 2012-2015 (see previous chapter). How the introduction of the topic as a permanent item during the inter-sessions process will contribute to progress in this situation will have to be assessed.

2.1.3 – States Parties (and groups of States Parties) having contributed to assessment of scientific and technological developments

REVIEW CONFERENCES	STATES PARTIES HAVING SUBMITTED CONTRIBUTIONS
***First* Review Conference**	**United Kingdom, United States, USSR***, Hungary, Sweden
***Second* Review Conference**	**United Kingdom, United States, USSR**, **Sweden**, Denmark, Czechoslovakia, Finland, Canada, Hungary on behalf of the Group of socialist States
***Third* Review Conference**	**United Kingdom, United States, USSR**, **Sweden**, **Australia, Canada, Switzerland,** Denmark, Czechoslovakia
***Fourth* Review Conference**	**United Kingdom, United States, Sweden, Switzerland,** Germany, Cuba, Finland
***Fifth* Review Conference**	**United Kingdom, United States, Sweden**, **South Africa,** Bulgaria
***Sixth* Review Conference**	(Report by the Conference Secretariat) **United Kingdom, United States, Sweden, Russia, Australia, Netherlands, Argentina, China,** Czech Republic, Portugal
***Seventh* Review Conference**	(ISU Report) **United Kingdom, United States, Sweden, Australia, South Africa, China, Germany,** Czech Republic, Netherlands, Poland, Portugal

*The three depositary States submitted a joint report.
In bold type: States Parties submitting more detailed contributions.

Among the States Parties contributing to this assessment, the United Kingdom, the United States and Sweden have regularly submitted information documents.

The number of countries sending documents with a view to contributing to the assessment of scientific developments was greatest for the seventh Review Conference. These contributions take various forms from country to country and are more or less detailed, mainly with the following: detailed information documents identifying all areas and developments relevant to the Convention, documents mainly describing the major advances since the previous Conference and brief contributions limiting the account to the situation of the State Party (briefing on developments to which its scientists have contributed or measures contributing to national implementation).

2.1.4 – States Parties (and groups of States Parties) mentioning issues linked with scientific and technological developments in their official statements during Review Conferences

REVIEW CONFERENCES	STATES PARTIES MENTIONING THESE ISSUES
First Review Conference	**Argentina** (other statements: NR)
Second Review Conference	NR
Third Review Conference	**Netherlands**
Fourth Review Conference	NR
Fifth Review Conference	**South Africa, Mexico, Canada,** Iraq, Switzerland, Ukraine
Sixth Review Conference	**European Union, United Kingdom, Russia, Japan, China, Malaysia, South Korea, Argentina, Brazil, Peru, Chil, New Zealand, Ukraine** Non-Aligned Movement, Algeria, South Africa, Holy See, Pakistan, India, France, Morocco, Bangladesh, Thailand, Australia (Note: statements by the **International Committee of the Red Cross**
Seventh Review Conference	**European Union, France, United Kingdom, Ireland, Denmark, Bulgaria, Switzerland, Norway, Russia, Ukraine, China, Japan, India, Pakistan, Bangladesh, Algeria, Morocco, Egypt, Australia, New Zealand, Brazil, Chile, Argentina, Costa Rica, JACKSNNZ, Non-Aligned Movement and other parties,, member-States of the Collective Security Treaty Organisation** Mozambique, Turkey, Romania, Indonesia, Philippines, Netherlands, United States, Mexico, Nigeria, Equador. (Note: statements by the **international Committee of the Red Cross**, **UNICRI** and the **OPCW**)

In bold type: States Parties laying greater stress on scientific and technical developments (for example, calling for changes in the review process), others simply mentioning their contribution to the threat and/or the necessity for taking them into account in the context of the Convention.

2.1.5 – States Parties (and groups of States Parties) making proposals relating to these questions in the context of Review Conferences

REVIEW CONFERENCES	STATES PARTIES MENTIONING THESE QUESTIONS
First Review Conference	**United Kingdom** (beforehand, a working paper on the basic documentation including a process for producing a report on scientific and technological questions)
Second Review Conference	**Group consisting of the German Democratic Republic, Hungary and the USSR** (proposal on Article V including setting up a scientific experts group)
Third Review Conference	**Bulgaria, United Kingdom, India, group consisting of Peru, Chile, Panama and Venezuela** (reaffirmation that Article I covers scientific and technical developments) **Group consisting of Peru, Chile, Panama and Venezuela** (proposal ro organise a Review Conference every five years)

Fourth Review Conference	**Chile, United States** (reaffirmation that Article I covers scientific and technical developments)
Fifth Review Conference	**Chile, United States, Mexico** (reaffirmation that Article I covers scientific and technical developments) **European Union, United Kingdom, Japan** (proposal to create a Scientific Consultative Committee)
Sixth Review Conference	**Non-Aligned Movement, European Union, Canada, and a group consisting of Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Equador, Guatemala, Mexico, Peru and Uruguay** (proposals for the inter-sessions process including scientific and technological developments in the topics to be addressed)
Seventh Review Conference	**India** (proposal with a view to setting up a structured and systematic review process for scientific and technological developments) **Group consisting of Australia, New Zealand and Japan (**proposal on setting up an annual review of scientific and technological developments) **Australia and Japan, United Kingdom** (creation as part of the inter-session process of a working group dedicated to reviewing scientific and technological developments) **United States** (other proposals for the inter-sessions process including scientific and technological developments in the topics to be addressed) **Poland** (proposal on the convergence of chemistry and biology and dealing with the possibility of developing joint answers between BTWC and CWC)

(Note: this list is not necessarily exhaustive and is based on available documents. This Table does not take account of proposals for paragraphs dealing with Article X and the agenda for the following Conference in the context of the review of Article XII).

It is apparent, seeing the proposals submitted by States, that the question of the scope of Article I was raised very early and that it seemed necessary to reaffirm that it did indeed cover scientific and technological developments. Offfical statements, like the proposals passed on at the most recent Review Conferences, convey the importance attached by States Parties to the problem and to the necessity for seeking to improve and structure the machinery for assessing these developments.

2.1.6 – The involvement of civil society

The number of non-governmental organisations participating in and submitting statements to the latest Review Conference demonstrates the involvement of civil society. Many of them laid stress on the review of scientific and technological developments (Pugwash, Pax Christi, SIPRI, *Harvard Sussex Program on Chemical and Biological Weapons*, VERTIC, IAP, *International network of engineers and scientists for global responsibility* (INES), *London School of Economics and Political Science* (LES), *University of Bradford Division of Peace Studies*). The proposals deal *inter alia* with the creation of working groups or a consultative body modelled on the OPCW Scientific Advisory Board, and increasing the frequency of reviews. Moreover, the representative of the *Harvard Sussex Program* laid stress in his statement on the convergence of chemistry and life sciences and its implications for both the CWC and the BTWC, supporting increased interaction between the two.

In particular several institutions have developed research programmes dealing with study of the consequences of scientific and technological advances in terms of arms control. Without attempting to give a comprehensive list, the following in particular may be mentioned:

- The **Royal Society** with, for example, a programme on neurosciences, one part of which is devoted to potential military applications and to applications in the area of neuroscience and neurotechnology safety. It is suggested among the recommendations that neurosciences should be taken into account when reviewing scientific and technological advances during the inter-sessions process, given the risks associated with incapacitating agents (for example, bioregulators)[34].

- The **Harvard Sussex Program** has a programme dedicated to studying the review process for scientific and technological developments in the context of the BTWC (http://hsp.sussex.ac.uk/sandtreviews/). By way of discussions the researchers have shown *inter alia* that the reasons given as to the necessity for these reviews might vary: keeping informed so as to be able to prevent abuses, but also a way of checking that there is proper implemention by nations, encouraging the implementation of machinery for cooperation and assistance (scientific diplomacy), making scientists aware, or even making it possible to return to the question of verification[35].

- The **IAP**, which organised a workshop at the Chinese Academy of Sciences in 2010 in cooperation with the International Union of Microbiological Societies (IUMS) and the International Union of Biochemistry and Molecular Biology (IUBMB) : « Trends in Science and Technology Relevant to the BTWC ». A summary report on this workshop was included in the document on scientific and technological advances prepared by the ISU[36]. In addition it co-organised a side-event on this topic at the seventh Review Conference.

- The **SIPRI**, with a report entitled « Science and Technology and their impacts on the Biological and Toxin Weapons Convention »[37].

2.1.7 – Convergence questions

This report has sought to identify all references to scientific and technological developments in the texts of official statements, final declarations and working documents. The field is wider than convergence, but as from the first Review Conference the developments considered had included areas and applications associated with this concept, even if the term is not cited, with biotechnologies in particular. This trend has increased, *inter alia* with the identification of nanotechnologies or

---

[34] The Royal Society, Brain Waves Module 3: Neuroscience, Conflict and Security, 2012.

[35] Revill J., McLeish C., « So you want to do 'something' on Science and Technology reviews in the Biological Weapons Convention? », 33rd Workshop of the Pugwash Study Group on Implementation of the CBW Conventions, Geneva, 3-4 December 2011.

[36] « Statement by the Biosecurity Working Group of the IAP: The Global Network of Science Academies », December 2011.

[37] Hart J., Trapp R., *Science and Technology and their impacts on the Biological and Toxin Weapons Convention – A synthesis report on preparing for the Seventh Review Conference and Future Challenges*. 2011.

bioinformatics as areas that should have been taken into account as part of a review of scientific and technological advances that might affect the Convention.

Even though the concept has always been hinted at, given the areas under consideration, the seventh Review Conference uses the term 'convergence' for the first time in a paragraph in the final document devoted to Article IX, noting "the increasing convergence of biology and chemistry and its possible challenges and opportunities for the implementation of the Conventions".

2.2 – Taking scientific and technological developments into account in the context of the CWC

2.2.1 – Machinery for assessing scientific and technological developments and their effect upon the Convention

This mechanism is based on the Scientific Advisory Board consisting of independent experts, whose task is to supply the Conference, the Executive Council and the States Parties with specialised opinions in the scientific and technical fields relevant to the Convention.

The Scientific Advisory Board has set up a Temporary Working Group on the convergence of chemistry and biology. The following topics have been considered in this context[38]:

i. Biologically mediated synthesis of chemicals;

ii. Chemical synthesis of agents of biological origin (for example, toxins or bioregulators) and replicating systems;

iii. The meaning of "manufacture by synthesis";

iv. Identification of scientific disciplines other than biology in which convergence with chemistry is apparent;

v. Positive potential fallout for the Convention from the convergence of chemistry and biology.

Moreover, a Temporary Working Group on verification has been set up, and met for the first time in March 2013. One of the items addressed deals with new or emerging technologies that might have added value for verification relative to existing capabilities. The importance of tools for sharing information, data analysis and communication among the various organisational units was stressed. One of the items in the discussion dealt with opportunities for improving the analytical capabilities of the *Verification Information System* (VIS) and for transferring inspection reports into the system[39].

[38] Report of the fourth meeting of the Scientific Advisory Board Temporary Working Group on the convergence of chemistry and biology, SAB.21/WP.2, 25 November 2013.

[39] Scientific Advisory Board, Report of the First Meeting of the Scientific Advisory Board Temporary Working Group on verification, SAB-20/WP.2, 27 March 2013.

2.2.2 – States Parties (and groups of States Parties) referring to questions linked to scientific and technological developments in their official statements or working documents in the course of Review Conferences

REVIEW CONFERENCES	STATE PARTIES HAVING REFERRED TO THESE QUESTIONS
First Review Conference	**South Korea** (document focusing on recent developments in chemical technology and the general nature of the Convention **Sweden** (document on technological progress and inspections in the industry)
Second Review Conference	**India, Singapore, South Korea, European Union and associated countries, Pakistan, Netherlands**, United States
Third Review Conference	**European Union, Luxembourg, Norway, Switzerland, France, New Zealand, Russia, Ireland, United Kingdom, Belgium, Australia, Romania, Germany, Kazakhstan, Japan, Indonesia, Philippines, India, Iraq, Singapore, African Group, Zambia, Zimbabwe, Nigeria, Costa Rica, Mexico**

(Note: this list is not necessarily exhaustive and is based on available documents. This Table does not take account of references to Article XI).

2.2.3 – The role of civil society

Civil society has had an especially important role from the outset. It actively supported the negotiations culminating in the adoption of the Convention. Its role has evolved since, and it contributes actively to implementation. Particular emphasis should be laid on the contribution of IUPAC to the review of scientific and technological developments and its collaboration with the Scientific Advisory Board. Civil society is involved in various areas with, for example, technical assistance (for example by VERTIC or SIPRI), public awareness or outreach, or even technical expertise (IUPAC)[40]. In addition, a number of NGOs and researchers have come together within the CWC Coalition, an international body whose task is to support the aims of the Convention.

The growing number of NGOs participating in Review Conferences should be noted. The organisation of an informal plenary session entitled " The multiple use of chemicals: Innovation, science, and security" introduced by Ahmet Üzümcü, the Director-General, was an innovation at the last Review Conference.

2.2.4 – Articles in the Convention that may be affected by scientific and technological developments

The question of the impact of scientific and technological developments on the range of the Convention has been raised, as in the case of the BTWC. Article II sets out definitions and criteria. The general-purpose criterion is defined in that Article, the text specifying toxic chemical products "regardless of their origin or method of production". So chemical products obtained by methods including stages biochemical in nature are

40 Trapp R., « Civil Society, Chemical Industry and the Chemical Weapons Convention », *CBW Magazine*, Décembre 2012.

included. Up to now, examination of this Article has led to the conclusion that these developments were duly taken into account.

Furthermore, it is particularly important to study the repercussions of these advances on the verification system laid down by Article VI. Special consideration should be given to new production procedures that might make it possible to obtain new chemical agents or to produce small quantities of chemical products, below the thresholds defined. In fact the number of other small low-output chemical production facilities (OCPF) that can easily be redirected is on the rise. Another example: nanoparticles used to modify the physico-chemical properties of chemical compounds, which might have a direct effect on the relevance of the declaration thresholds defined. A certain number of chemical products classed in Tables 1, 2 and 3 or as discrete organic chemicals (DOC) are subject to declaration, with mass thresholds for Table 2 and 3 products and DOC, as well as low concentration thresholds for Table 2 and 3 products.

Scientific and technological advances will also have an effect in the case of national implementation, provided for by Article VII. For example, they may have the power to make national monitoring more complicated.

Their contribution must also be considered from the point of view of Article X on assistance and protection. They may in fact help in perfecting means of detection, identification, protection or treatment. Lastly, consideration should be given to how international cooperation and exchanges dealing with these advances may contribute to sustainable development or public health, in the context of implementation of Article XI on economic and technological development.

2.2.5 – Convergence issues

Although the term convergence cannot be found in the information document drafted by the Scientific Advisory Board with the first Review Conference in mind, nevertheless the consequences of advances in areas covered by biology are certainly taken into account. The final report of the first Review Conference stresses the importance of considering scientific and technical progress, but the issue of convergence is not touched upon, either expressly or by implication.

The first report by the Technical Secretariat on reviewing the operation of the Convention with the second Review Conference in mind states that the system of verification should be adapted in order to take account of scientific and technical advances, including the convergence of chemistry and biology. The report supplied by the Scientific Advisory Board from the perspective of the second Review Conference clearly refers to the issue of convergence of chemistry and biology, repeating the term several times. In addition to the paragraph dedicated to convergence of chemistry and biology, several of the points considered by the experts were within the province of technological convergence, at least in part, like for example nanotechnologies, systems of administration for medicines and using biocatalysis for industrial production. The final report returns to the role of the Scientific Advisory Board alone, without referring to convergence issues.

As regards the third Review Conference, the report by the Technical Secretariat on reviewing the operation of the Convention and the report by the Council give prominence to both and bring out the issue of convergence. In the final report the Conference notes the growing convergence of chemistry and biology and stresses the importance of the Scientific Advisory Board's temporary working group on convergence.

2.3 – *Convergence of the two Conventions: focus on some technologies and applications*

2.3.1 – *Systems biology*

Systems biology seeks to study the functioning of biological systems from every angle, integrating the various levels of information. Thus François Képès defines it as the science of systems analysis of the dynamic and spatial behaviour of interaction networks[41]. One of its applications is the study of the immune system, which is a complex system though rarely seen as such. A better knowledge of immunity mechanisms will make it possible to develop new therapeutic strategies, but also to examine how to weaken or bypass immunity defences[42].

Systems biology has developed from disciplines grouped together under the title "omics", whose development should be put in the context of improvement of knowledge thanks to the Human Genome Project. It is based more specifically on functional genomics. The latter corresponds to that part of genomics that studies the function of genes, their regulation and interactions by their expression products, RNA and proteins, structural genomics studying the physical and organisational structure of the genome and the proteome (French General Commission of Terminology and Neology, 2006). Work in the field of funtional genomics is making the development of quantitative models of organisms and cells possible. It also contributes to identifying and validating new targets and innovative therapeutic strategies on the basis of study of gene expression regulation mechanisms under normal or pathological conditions. Inducing overexpression, or on the contrary extinction, of certain genes may make it possible to identify those involved in pathologies of genetic origin.

Progress regarding sequencing techniques is a substantial advance in this discipline. One of the first sequencing methods, which is still the one most widely used in the world at present, is the Sanger enzymatic method (the Maxam-Gilbert chemical method is hardly ever used now). The latter remains slow and expensive. The introduction of new-generation sequencing or NGS (or massively parallel sequencing) may be described as a technological leap forward. This procedure is used above all for exome sequencing, which corresponds to the DNA coding sequences alone, for reasons of cost, time and the generation of more reliable data[43]. These advances have been accompanied by such a reduction in sequencing costs that now the limiting factors for many experiments are time and the cost of reagents for the preparation of samples, and consequently of libraries[44]. Thus high-throughput sequencing is opening up new prospects for the identification of genes involved in hereditary diseases, genetic

[41] Képès F., (Centre de recherche en épistémologie appliquée, Ecole polytechnique, CNRS), « La biologie de synthèse comme vecteur d'un renouveau de biotechnologie (présentation, plateforme « Génétique et société ») », GenoToul, May 2011.

[42] Nixdorff K., « A l'attaque du système immunitaire », *Forum du désarmement,* 2005;1:29-40.

[43] Rauch A., « Le séquençage nouvelle génération – Un saut quantique dans l'explication des maladies génétiques », *Forum Med Suisse,* 2012;12(3):44-46.

[44] Rohland N., Reich D., « Cost-effective, high-throughput DNA sequencing libraries for multiplexed target capture », *Genome Res,* 2012;22(5):939-46.

predisposition factors or even tumoral genetic anomalies by distinguishing between principal and secondary mutations. These tools are also finding applications in diagnosis[45]. In addition they involve consideration of the ethic dimension, because of their potential.

2.3.2 – Synthetic biology

The convergence of chemistry and biology is obvious at the level of chemical and biological agent production methods. In fact it is possible to produce chemical compounds by biological production methods, *inter alia* by taking advantage of biotechnologies, but also to obtain biological products by chemical production methods.

These two prospects can be found in synthetic biology: it is a new approach to biology, multidisciplinary, covering in general the design and synthesis of biological components and systems, which either do not exist in nature or are produced by modifying existing components. Although synthetic biology is a new discipline, resulting from the convergence of knowledge and techniques originating from other disciplines such as genetic engineering, physics, nanotechnologies, biotechnologies, electrical and mechanical engineering or even computer simulation, its frontiers are still undefined. There is no generally accepted definition. These are two examples of definitions, at the European level:

> *"Synthetic biology is an emerging area of research that can broadly be described as the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems". (Royal Society, London));*

> *"Synthetic biology is the engineering of biology: the synthesis of complex, biologically based (or inspired) systems which display functions that do not exist in nature. This engineering perspective may be applied at all levels of the hierarchy of biological structures – from individual molecules to whole cells, tissues and organisms. In essence, synthetic biology will enable the design of 'biological systems' in a rational and systematic way". (Synthetic Biology, Applying Engineering to Biology, Report of a NEST High-Level Experts Group).*

Many applications may be considered, for example renewable energy production, development of therapeutic treatments, or environmental decontamination. For example, the pharmaceutical industry is investing in this area and the synthesis with a view to industrial production by Sanofi of a precursor of artemisinin, an active substance used in the treatment of malaria, is an important step forward[46]. Synthetic biology is a rapidly developing branch of the bioeconomy.

Moreover several examples also illustrate the new prospects afforded by the development of synthetic biology, but which also give rise to controversy as to the use of the knowledge and techniques deployed[47]: the synthesis of a virus with the

---

[45] Le Gall J-Y., « Techniques d'analyse du génome et de son expression : applications médicales », *Bull Acad Natle Méd,* 2012;196(1):151-71.

[46] Meunier B., « Les molécules hybrides comme stratégie de création de nouveaux agents anti-infectieux », *Compte Rendu Chimie*, 2011;14(4):400-405.

[47] Samuel G., Selgelid M., Kerridge I., « Back to the future: Controlling synthetic life trade in DNA sequences », *Bulletin of the Atomic Scientist*, 2010;66(5):9-20.

biochemical and pathogenic characteristics of a poliovirus[48], obtaining a virus comprising the 8 genomic segments of the 1918 strain and recombinant viruses comprising some of those segments by reverse genetics[49] and, more recently, obtaining a copy of the genome of a bacterium, *Mycoplasma genitalium*[50], by *in vitro* recombination of "cassettes" resulting from assembly – based on the natural sequence – of DNA segments obtained by chemical synthesis, cloning of these intermediate assemblies and identification of those showing good sequences, then lastly final assembly by clonage on yeast and identification of a clone with the sequence sought (however, a gene involved in pathogenicity has not been recovered and markers have been introduced to differentiate the synthetic genome). This genome could not replicate independently, but later this research culminated in creation of the first bacterial cell controlled by a genome obtained by synthesis and assembly. This synthetic genome of *Mycoplasma mycoïdes* (including as previously markers and deletions) was introduced into a cell of *Mycoplasma capricolum*. The new *M. mycoïdes* cells, controlled by a synthetic chromosome, have the expected phenotypical properties and are capable of self-replication[51].

Ethical questions, but also questions connected with intellectual property, protection, safety and security are among the principal concerns associated with this area of innovation[52],[53]. The problems of duality were stated as follows in a report by the American Academy of Sciences:

> *« DNA synthesis technology could allow for the efficient, rapid synthesis of viral and other pathogen genomes – either for the purposes of vaccine development, or for malevolent purposes or with unwanted consequences »*[54].

In addition, it should be borne in mind that synthetic biology may also be used to synthesise chemical structures that do not exist in nature, like for example nucleotide sequences[55].

---

48 Cello J., Paul AV., Wimmer E., « Chemical synthesis of poliovirus cDNA: generation of infectious virus in the absence of natural template », *Science*, 2002 Aug 9;297(5583):1016-8.

49 Tumpey TM., Basler CF., Aguilar PV., Zeng H., Solórzano A., Swayne DE., Cox NJ., Katz JM., Taubenberger JK., Palese P., García-Sastre A., « Characterization of the reconstructed 1918 Spanish influenza pandemic virus », *Science*, 2005 Oct 7;310(5745):77-80.

50 Gibson DG., Benders GA., Andrews-Pfannkoch C., Denisova EA., Baden-Tillson H., Zaveri J., Stockwell TB., Brownley A., Thomas DW., Algire MA., Merryman C., Young L., Noskov VN., Glass JI., Venter JC., Hutchison CA. 3rd, Smith HO., « Complete chemical synthesis, assembly, and cloning of *Mycoplasma genitalium* genome », *Science*, 2008;319(5867):1215-20.

51 Gibson DG., Glass JI., Lartigue C., Noskov VN., Chuang RY., Algire MA., Benders GA., Montague MG., Ma L., Moodie MM., Merryman C., Vashee S., Krishnakumar R., Assad-Garcia N., Andrews-Pfannkoch C., Denisova EA., Young L., Qi ZQ., Segall-Shapiro TH., Calvey CH., Parmar PP., Hutchison CA 3rd, Smith HO., Venter JC., « Creation of a bacterial cell controlled by a chemically synthesized genome », *Science*, 2010;329(5987):52-6.

52 Anderson & *al*., « Engineering and ethical perspectives in synthetic biology », *EMBO Reports*, 2012;13):584-90.

53 IRGC, « *Synthetic Biology: Risk and Opportunities of an emerging field* (Concept Note) », International Risk Governance Council, Geneva. 2008.

54 Committee on Advances in Technology and the Prevention of Their Application to Next Generation Biowarfare Threats, National Research Council, *Globalization, biosecurity, and the future of life sciences,* The National Academies Press, Washington, DC. 2006.

55 Chiarabelli C., Stano P., Luisi P.L., « Chemical approaches to synthetic biology », *Current Opinion in Biotechnology*, 2009;20:492-97.

Thoughts on issues in synthetic biology integrating questions of safety are not confined to the Anglo-Saxons A report by the Parliamentary Office for the Evaluation of Scientific and Technical Choices (OPECST) entitled "Les enjeux de la biologie de synthèse" submitted by Mme G. Floraso was published in 2012. It stresses that European countries became concerned very early about ethical and security aspects, including risks connected with possible abuses of synthetic biology technologies linked to its dual-use potential. Thus the defence and security sector is concerned both by development prospects and by questions of security. So a report on synthetic biology has been produced by the General Armaments Council. Faced with a need to monitor dual technologies as part of the functions of the Australia Group, defence and national security officials have ordered reports on this topic with, for example, thoughts on the development of a system making it possible to channel and control exports of nucleotides[56].

2.3.3 – Other ways of producing chemical compounds by biological production methods

Several other methods are in the process of being developed and improved[57]:

biocatalysis, an alternative to organometallic catalysis making it possible to synthesise chemical products of value thanks to the enzymatic activity of enzymes that will accelerate chemical reactions or act as catalysts. Various procedures can be employed[58]. Progress in DNA sequencing and gene synthesis have led to substantial advances, making it possible to perfect biocatalysts by virtue of methods of studying protein structures (design) and engineering[59],[60].

Using biocatalysts is advantageous because procedure performance is improved, with the synthesis of optically active compoundss, since enzymatic reactions are generally stereoselective. They are also regarded as being less polluting because there is less use of organic solvents and so part of green chemistry. However, there may be a risk in the long term with, for example, the use of halogenases to produce toxic chemical compounds with chlorine or sulphur in their composition[61].

"Molecular farming" (or "biopharming"), consisting of production from transgenic plants of recombinant proteins like, for example, monoclonal antibodies, cytokines, enzymes or subunit vaccines[62]. Advances in molecular biology and in the biotechnology field have made it possible to develop this approach. It has been possible to obtain a monoclonal antibody for the prevention of rabies from transgenic plants[63].

---

[56] Binder P., « L'impact de la bioéconomie sur le secteur de la défense-sécurité : l'exemple de la biologie de Synthèse », *Annales des Mines – Réalités industrielles*, 2013;1:83-90.

[57] Tucker J., « The convergence of biology and chemistry: Implications for arms control verification », *Bulletin of the Atomic Scientist*, 2010;66(6):56-6.

[58] Nestl BM., Nebel BA., Hauer B., « Recent progress in industrial biocatalysis », *Curr Opin Chem Biol*, 2011;15(2): 187-93.

[59] Meyer H-P., Turner J., « Biotechnological manufacturing options for organic chemistry », *Mini-Reviews in Organic Chemistry*, 2009;6:300-306.

[60] Bornscheuer UT., Huisman GW., Kazlauskas RJ., Lutz S., Moore JC., Robins K., « Engineering the third wave of biocatalysis », *Nature*, 2012;485(7397):185-94.

[61] Tucker, 2010.

[62] Melnik S., Stoger E., « Green Factories for Biopharmaceuticals », *Curr Med Chem*, 2013;20(8):1038-46.

[63] Ko K., Koprowski H., « Plant biopharming of monoclonal antibodies », *Virus Research*, 2005;111:93-100.

As regards production of biological molecules by chemical production methods, the possibility of peptide synthesis by the chemical route,for example by chemical ligation, which can be mediated enzymatically, or solid phase synthesis should also be taken into account. Some toxins are peptidic in nature, for example toxins from scorpion or snake venoms, like bioregulators.

2.3.4 – Nanotechnologies

European policy on nanomaterials is based on the action plan adopted by the European Commission. In 2008 the Commission circulated recommendations on a Code of Conduct for responsible nanoscience and nanotechnology research[64]. A second regulatory review on nanometerials was also published, in 2012[65].

In the field of public health, nanosciences coupled with neurosciences make it possible to develop new therapeutic strategies. Administration of molecules directly at the level of the brain is part of the lines of reseach, in particular for the treatment of neurodegenerative diseases or brain tumours. However, crossing the blood-brain barrier (BBB) is a major obstacle. Although liposoluble substances can generally cross this barrier, non-liposoluble or ionised substances cannot pass. In addition, many liposoluble therapeutic molecules cross this barrier less readily than might be expected according to their solubility. So the use of nanoparticles is an especially interesting avenue, not merely because of their size but also because of their specific physico-chemical properties. Substantial advances have been made in this area. For example, a team has succeeded for the first time in demonstrating the active delivery in mice of nanoparticles to brain metastases by way of macrophages from circulating monocytes injected systemically, thus making it possible to bypass the BBB[66].

Various other routes have been studied for the targeted delivery of nanoparticles intended for vectorising medicines, including medicinal genes. So chitosan nanoparticles are of great interest as vectors, making it possible to improve the solubility and stability of medicines, as well as improving their efficacity and reducing their toxicity[67]. These delivery routes include *inter alia* the ocular and nasal routes. The nasal route in particular is of major interest, in particular for administering vaccines, but also medicines intended to target the brain and which would not pass the BBB, while limiting peripheral exposure (to limit the associated side-effects). In fact it makes it possible to bypass the BBB and reach the brain by way of the olfactory nerve[68]. It is taking shape as a promising non-invasive method of delivery for bioactive molecules such as hormones, neuropeptides, medicinal genes, growth factors, insulin or even ocytocine. Numerous applications are being considered, including treatments for pathologies and states involving the central nervous system like Parkinson's disease and

---

[64] Commission recommendations dated 07/02/2008 concerning a code of conduct for responsible nanosciences and nanotechnologies research.

[65] Communication by the Commission to the European Parliament, the Council and the European Economic and Social Committee. *Second regulatory review on nanomaterials*, 3 October 2012.

[66] Choi M-R., Bardhan R., Stanton-Maxey K., Badve S., Nakshatri H., Stanz K., Cao N., Halas N., Clare S., « Delivery of nanoparticules to brain metastases of breast cancer using a cellular Trojan horse », *Cancer Nanotechnol*, 2012;3(1-6):47-54.

[67] Wang J & *al.*, « Recent advances of chitosan nanoparticles as drug carriers », *Int J Nanomedicine*, 2011;6:765-74.

[68] Gizurarson S., « Anatomical and histological factors affecting intranasal drug and vaccine delivery », *Curr Drug Delivery*, 2012;9(6):566-82.

Alzheimer's disease, Huntington's disease, depression and anxiety, convulsions or even alimentary disorders and addictions[69]. With this in view, in 2012 the American Army made a grant of 3 million dollars to an Indiana University School of Medicine team to develop and perfect a nasal spray for administering a hypothalamus hormone (TRH or *thyrotropin-releasing hormone*). Biodegradable nanoparticles have been used as vectors in experiments on rats. Administration by mouth or injection is not possible, because then it deteriorates too quickly. The aim is to prevent suicides. A medicine like this might be given in an initial phase, to obtain quick action while waiting for antidepressants to take effect.

However, these applications should not let us forget the risks to health that nanoparticles may be. Thus research by teams from the Atomic Energy and Alternative Energies Commission and the Joseph-Fournier University in Grenoble has shown that titanium dioxide nanoparticles might cause cerebral disturbances in the event of exposure to large doses. Accumulation of these in the endothelial cells may cause the blood-brain barrier to break, as well as cerebrovascular inflammation. These results were obtained on an *in vitro* model so should be supplemented[70]. Previous studies on rats had shown that titanium dioxide nanoparticles could be detected in the brain after intranasal delivery.

Moreover, for example in the field of detection in order to improve sensor speed and selectivity and to continue miniaturisation, research is under way on using carbon nanotubes for gas sensors and biosensors and on silicon nanowires for biosensors (with, for example, the NANBIOSENSOR, NANBIODETECTOR and NANOBATS2 projects, funded as part of the French National Research Agency PNANO 2005 and 2006 programme).

The nanotechnologies are also an important area of research for the armaments sector. Thus Jürgen Altmann, a physician at Dortmund University, has taken a particular interest in nanotechnologies from a military viewpoint, but also from that of arms control[71]. Potential applications related to the context of this study include, for example:

- ⇨ miniaturised more sensitive, more selective and less expensive sensors for the detection and identification of chemical and biological agents (e.g., using carbon nanotubes for gas sensors and biosensors and silicon nanowires for biosensors);
- ⇨ vectorisation systems for targeted delivery of medicines;
- ⇨ smaller and more precise vectors;
- ⇨ more efficient powders and explosives;
- ⇨ miniaturised and more efficient propulsion systems and energy sources;
- ⇨ miniature satellites and launchers;
- ⇨ high-performance miniaturised energy sources;

[69] Chapman C., Frey W. 2nd, Craft S., Danielyan L., Hallschmid M., Schiöth H., Benedict C., « Intranasal treatment of central nervous system dysfunction in humans », *Pharm Res*, 2012.

[70] Brun E., Carriere M., Mabondzo A., « In vitro evidence of dysregulation of blood–brain barrier function after acute and repeated/long-term exposure to TiO2 nanoparticles », *Biomaterials,* 2012 ;33:886—896.

[71] Altmann J., « Limiting military use of nanotechnology and converging technologies » (Conference), 2005. http://cgi-host.uni-marburg.de/~nano-mr/downloads/s3/altmann_paper_final.pdf

- ⇨ new more resistant materials;
- ⇨ faster miniaturised communication systems and computers.

2.3.5 – Bioinformatics and computational tools

The exponential growth in the volume of biological data, together with their heterogeneity and the complexity of models, is giving rise to challenges in terms of processing and analytical capability[72]. Thus technological improvements in the collection, storage capacity and processing of biological data or even simulation are finding practical applications in the life sciences. Bioinformatics, a recent discipline at the interface of computing, biology, mathematics and physics, is making it possible to meet this challenge. In English the term *bioinformatics* covers the development of infrastructure and tools, such as algorithms, statistical models or database software, whereas *computational biology* is used for the development and implementation of methods of analysis, using mathematical models, to solve biological problems. The development of this discipline is closely linked with advances in omic approaches, whose aim is to grasp the complexity of the living being in its entirety.

The applications are especially important for biomedical research. It contributes to a better understanding of the mechanisms involved in cell function, as well as those that operate in the appearance and development of certain diseases, so opening the way to developing innovative therapeutic strategies and identifying new therapeutic targets. Bioinformatics is also called upon for research and the development of new vaccines or medicines. Using simulation by digital modelling, it makes it possible to forecast the three-dimensional structure of molecules, to study molecular interactions or to predict toxicity and side-effects as from the discovery phase. So recourse to bioinformatics makes it possible to look forward to a reduction in the costs and length of the development cycle for a medicine. Moreover in this context personalised medicine, taking the specific molecular and biological characteristics of patients into account, has become a possibility. This (pharmaco-genomic) approach aims to improve diagnosis and prognosis, and to achieve individualisation of treatments based on study of the genome and identification of molecular markers. This involves *inter alia* being able to predict the efficacity, but also the toxicity, of treatment in a patient.

Thus in 2010 a list of more than 1400 bioinformatic tools and databases accessible on line had been compiled. Common interfaces, like the BioCatalogue, have been created, to facilitate access[73]. It incorporates the content of other sources, but also allows manual registration of new Web services and suggests a classification based on ontology. Harmonised explanations describing the functions performed by these services and how to use them are also added[74].

The R&D BioIntelligence programme, supported by Dassault Systems and SoBios, illustrates the advantages of using bioinformatics tools in the field of life sciences. Intended for the pharmaceutical, cosmetic and phytosanitary industries, its aim is to develop an integrated software environment, a computing tool that should make it

---

[72] Nexon E., « Bio-informatique et biologie computationnelle », *Observatoire de la Non-Prolifération*, 2013;77.

[73] www.biocatalogue.org

[74] Bhagat & al., « BioCatalogue: A universal catalogue of web services for the life sciences », *Nucleic Acids Res*, 2010;38:689-94.

possible to anticipate failures and above all to promote and speed up the decovery and development of innovative new molecules and biological entities. This simulation and modelling platform should be linked to biological databases.

These matters are taken into account as part of the review of the impact of scientific and technical advances on the Conventions prohibiting biological and chemical weapons. Bioinformatics forms part of these developments, like other areas with which it interacts closely such as biotechnologies, genomics or proteomics.

2.4 – Convergences and impacts affecting the BTWC and the CWC

There is increasing convergence of sciences and technologies affecting both these Conventions, especially in chemistry and biology. This is particularly obvious with regard to production technologies, with the use of biological or biologically mediated processes for the manufacture of chemical products and the chemical synthesis of biological molecules or systems. Capabilities for modelling, computer-aided design and engineering of enzymes are increasing, allowing the creation of new biocatalysts that can be used in synthetic biology. There is also rapid development of capabilities for organism manipulation and modification, with recombinant DNA and synthetic biology technologies. In addition the impact of enabling technologies on convergence phenomena should be stressed, for example with developments in DNA sequencing or advances in computing and computational tools. The convergence of chemistry and biology with nanotechnologies should also be noted.

During the last decade, however, there has been no major advance that could have called the scope of the Conventions or the nature of research into question. Although for the moment there seems to have been no change of paradigm yet, nevertheless it should be borne in mind that there might be scientific breakthroughs in certain areas that could have an effect on the Conventions. With this mind, the Organisation for the Prohibition of Chemical Weapons (OPCW) Scientific Advisory Board's temporary working group on convergence has recomended monitoring advances in the following fields: production technologies, systems biology and synthetic biology and nanotechnologies.

Scientific and technological developments in the context of both the CWC and the BTWC: some key points

General trends
Scientific and technical convergence phenomena (especially the convergence of chemistry and biologyy)
Improvements in knowledge in the life sciences field, especially on biological processes
Dissemination of knowledge and capabilities
Increases in tangible and intangible flows
The role of the media and the views of society
Examples of advances that might involve risk
A better understanding of the mechanisms of action and effects of chemical agents (toxicity) and biological agents (pathogenicity, virulence, etc.)
Perfecting new chemical and biological agents (especially mid-spectrum agents such as toxins and bioregulators)
Improving production technologies (*inter alia* biological or biologically mediated processes for the manufacture of chemical products and chemical synthesis of molecules or biological systems)
Improving techniques for dispersion and targeted delivery
Fields and disciplines relevant to both Conventions and of particular concern in the context of monitoring
Production technologies
Biotechnologies, systems biology and synthetic biology
Nanotechnologies
Neurosciences
Areas of development with possible beneficial applications
Detection
Diagnostics
Identification
Protection
Prophylaxis and curative treatment
Enabling technologies
DNA sequencing and synthesis
Technologies – omic
Synthetic biology
Nanotechnologies
Bioinformatics and computational tools

Sources : Report; ISU; OPCW Scientific Advisory Board's temporary working group on convergence; J. Hart & R. Trapp, Science and technology and their impacts on the Biological and Toxin Weapons Convention (2011) ; OECD, Future prospects for industrial biotechnology (2011).

It seems obvious that the convergence of chemistry and life sciences is having an effect upon both Conventions. Besides, it should be stressed that although these Conventions do not themselves converge they do overlap in part, and both take into account certain chemical compound categories, in particular toxins and bioregulators. Coordination of the two systems will make it possible, *inter alia*, to avoid these chemical compounds being left out in the end by either of these instruments. In this context of convergence, the necessity for these two systems to be brought closer to each other has been emphasised on many occasions, in both forums. However, scientific and technological convergence does not imply legal or political convergence by the various treaties.

The CWC and the BTWC both include a general-purpose criterion, making it possible to take future scientific and technical advances into account. So it is not technologies but purposes that are prohibited. Given the developments, however, it seemed essential to reaffirm the scope of Articles II and I of these Conventions respectively, studying the potential consequences of these advances. Although the problems linked to convergences are clearly identified, it nevertheless often proves difficult to decide how the implementation process should be adapted.

The review mechanisms of the two Conventions differ greatly, because the CWC has a Scientific Advisory Board. As regards the BTWC, the ISU which, it should be noted, has a variety of assignments and a limited team, is involved. The principal change affecting the BTWC has been to introduce the question of scientific and technological developments as a permanent item on the agenda of meetings during the inter-sessions process. However, this lack of symmetry between the two Conventions does not prevent exchanges. Besides, the the CWC Scientific Advisory Board's temporary working group on convergence has concluded *inter alia* that it would be desirable to establish a structured approach in order to have contacts between the two Conventions.

It is difficult to predict the course of scientific and technological developments in areas characterised by uncertainty, like for example biotechnology and nanotechnology, and so anticipate breakthroughs. This finding may lead to an analysis based on a sociotechnical model, rather than the technological determinism model often used in assessing the development of biological and chemical threats. In this model, which is more complex, interactions between technologies and society must be taken into account by integrating political, social, economic and scientific context factors. The emergence of a new technology that may be dual-use does not mean that it will necessarily be exploited, or even abused. In addition, all areas do not evolve at the same rate. The question therefore arises whether all developments should be treated alike as part of a review process or whether subjects that should be analysed in greater detail should be selected.

So taking convergences into account is a real challenge, also involving managing to monitor advances in areas which had not necessarily been monitored before. Moreover, it calls for a multidisciplinary approach,in order to identify issues peculiar to each area. It also seems important for States Parties to be able to rely on the expertise of specialists still directly involved in research, not only in life sciences but also in other areas that may contribute to scientific and technological advances relevant to the Conventions, in view of convergence phenomena. They should also be made aware of arms control and non-proliferation issues, and of the Conventions accordingly.

More generally, it is vital to stress the importance at national level of raising awareness and of training intended for scientists. Some of those responsible for developments relevant to the Convention may be unaware of the potential consequences in terms of security. It may sometimes prove difficult to strike a balance between publishing scientific information and the demands of security. Future scientists must be made aware and given a sense of responsibility at the outset. The aim of this approach is to gain influence over the long term and therefore over the scientific practices of these future professionals, with the development of a culture of security. It is therefore necessary for this purpose to find attractive ways of interesting students on the courses in question.

2.5 – Recommendations

Recommendation 2**:** Assessment of the potential consequences of advances linked to scientific and technological convergences involves having permanent monitoring machinery available at national level based on a multidisciplinary approach, in view of convergence phenomena. to Creating a new dedicated structure does not seem appropriate, because there are already structures and committees with targeted expertise that can be used (for example, the Observatory for Micro and Nano Technologies, the High Council for Biotechnology, the future Biosecurity Surveillance Committee, certain university laboratories or scientific societies, etc.). After making the persons involved aware of questions of security, proliferation and arms control, what is required for the most part is to organise machinery for the upward flow of information, possibly spontaneous, and collection of this information and assessments. An ad hoc multidisciplinary working group including representatives of the various ministries concerned and scientists still involved in research would be responsible for summarising this information and drafting a report.

Recommendation 3: A study of the way of benchmarking methods for assessing scientific and technological risks and assessment criteria might be considered.

Recommendation 4: Organising an annual seminar (modelled on the one organised by the Foundation for Strategic Research for the Delegation for Strategic Affairs in February 2013 but more broadly based) might help to bring together and raise the awareness of those active in very different fields, some of whom had been only slightly affected by these questions of security and proliferation up to now. This semilar might contribute to the business of assessment.

Recommendation 5: At the next CWC and BTWC Review Conferences France might contribute to the review of scientific and technical developments by submitting its own assessment of scientific and technological advances and their impact on the Conventions, stressing convergence phenomena.

Recommendation 6: Fostering stakeholder accountability is a major effort, as emphasised by the proposal by France at the last BTWC Review Conference. In order to encourage information for scientists and other stakeholders, an internet page dedicated to security questions linked with scientific and technological developments and stressing questions of convergence might be set up (for example, on the French Ministry of Higher Education and Research site). In order to assist a drive for increasing awareness, training or setting up risk management plans, teaching aids (for example, slide shows and briefing summaries on the aims of the Conventions and national legislation, bodies to be contacted if need be, etc.) might be made available with a view to assisting teachers or staff.

In order to keep scientific and academic communities informed on these questions, an annual or biennial newsletter might be sent through the relevant professional associations and scientific societies, after a drive for increasing the awareness of contacts in these bodies (developments in legislation, training initiatives, focus on an example, etc.).

Recommendation 7: Following the proposal of a peer review mechanism for the BTWC by France at the last Review Conference, the Ministry of Foreign Affairs organised a pilot exercise in December 2013, with the collaboration of the Foundation for Strategic Research. If this type of exercise is repeated, a briefing on implementation of the measures aimed at fostering stakeholder accountability might be organised.

Recommendation 8: Although France has always been particularly involved in scientific cooperation and research, the emergence of the scientific diplomacy concept based on acknowledgement of the importance of science in diplomatic action has encouraged in-depth study to develop a real strategy. More specific examination of how to link the implementation of Articles X and XI of the BTWC and the CWC respectively with this strategy may prove interesting.

3 – Autonomous weapon systems

Autonomous weapon systems may be defined as systems which, once activated, can select and engage targets, which may be human, without intervention by an external operator. The consequences of action may be lethal, and these weapon systems are sometimes also called "lethal autonomous robots" (LAR) or "killer robots".

3.1 – State of the art

Several principal weapon system or robot categories can be distinguished, according to the degree of human intervention:

- ⇨ Those requiring interaction in real time with one or more operators, even if they can perform certain acts independently, and so for which the human factor must be taken into account *("Human-in-the-loop").* Drones, for example, fall into this category;
- ⇨ Those that can act independently of any command by an operator, but which remain under supervision by one or more human beings, who receive information continuously. In case of need these can immediately resume control and intervene from time to time at programming level *("Human-on-the-loop").* This approach makes it necssary to develop situational awareness differing from that required in the previous case, mobilising other types of cognitive capability[75];
- ⇨ Those that can work independently of any human control *("Human-out-of-the-loop"),* but differentiating automation and autonomisation.

Automation does not imply that henceforth human activities are performed by the system, but that these evolve. In addition it is not based on a binary approach (automated/non-automated task), and the level of automation must be decided upon when the system is designed. Thus various stages may be considered, on the basis of interactions between human beings and systems according to the level of automation of decision-making and actions. Autonomous weapon systems may be regarded as the ultimate stage.

Developments relating to autonomous weapon systems are rapid, linked in particular to advances in artificial intelligence and robotics. Nevertheless it is still quite difficult to assess the level of advance in R&D programmes, given the demands of national security and confidentiality. At present no fully autonomous system has yet been deployed on the ground. On the other hand there are already systems with functions characterised by a certain level of autonomy that can be lethal. Countries such as the United States, South Korea, Israel, Japan and the United Kingdom have developed such systems and in some cases are using them under operational conditions. China and Russia are also said to have development programmes.

[75] Hew P., Lewis E., Radunz P., Rendell S., *Situation Awareness for Supervisory Control: Two Fratricide Cases Revisited*, 15th International Command and Control Research and Technology Symposium, Santa Monica, 2010.

Systems that may be looked on as precursors of fully autonomous systems include, *inter alia*:

- ⇨ The Raytheon Phalanx CIWS, installed on ships of the United States Navy, is an antimissile system capable of detecting, tracking and automatically engaging airborne threats, including missiles and aircraft, according to parameters such as speed and altitude. It is computer-controlled and radar-guided[76].

- ⇨ The C-RAM or *U.S. Counter Rocket, Artillery and Mortar System*, whose development is based on integrating existing technologies, gives early warning in the event of indirect fire and can automatically intercept rockets and mortar bombs.

- ⇨ The X-47B drone, developed by Northrop Grumman, has been tested at sea, showing that it could manœuvre close to another aircraft and could be catapult-launched from and land on an aircraft carrier[77]. It is autonomous in flight, on the basis of preprogrammed flight plans, even though its manœuvres are still tracked by operators with portable command and control sets. Human interventions will be limited to sending and receiving information, the system providing piloting. Moreover it can be refuelled in flight. Though capable of carrying bombs, it is intended mainly for observation missions.

- ⇨ The SGR-A1 robot sentries, developed by a consortium led by Samsung Techwin Co., are deployed in the demilitarised zone between the two Koreas[78]. Any person entering this zone is automatically treated as an enemy. They are equipped with temperature and movement sensors making it possible to detect and track targets. In the event of non-recognition they can send an audible warning or open fire, after autorisation. So these robots, which can distinguish between a human being and an animal or an object, are still under human supervision but have an automatic mode[79].

- ⇨ The Harpy (*"Fire and forget"* type*)* system developed by Israel Aerospace Industries is configured to detect, attack and destroy radars. These systems are launched from a land vehicle or from a shipborne launcher[80]. Hadop has been developed on the basis of this system.

- ⇨ The Taranis system has been designed to provide an intercontinental mission capability, with the aim of identifying targets, attacking them and capable of avoiding missiles automatically. The system will be controlled by an on-board computer and will rquire autorisation by the operator only to attack the target[81]. It is to be tested in Australia in 2013.

---

[76] http://www.raytheon.com/capabilities/products/phalanx/

[77] Chachaty H., « Le X-47B a repris ses essais en mer », *Le Journal de l'Aviation*, 13 novembre 2013.

[78] « Army tests machine-gun sentry robots in the DMZ », *Yonhap News Agency*, 13 juillet 2010.

[79] « South Korea deploys robots capable of killing intruders along border with North », *The Telegraph*, 13 juillet 2010.

[80] http://www.iai.co.il/

[81] Gray R., « British stealth drone to undergo first test flight », *The Telegraph*, 13 janvier 2013.

The battlefield introduction of autonomous weapon systems is likely to alter warfare significantly, without it being possible yet to assess the scope of this development completely, if it comes to anything. Might not resorting to autonomous machines instead of combatants, limiting the risk of human casualties, be likely to facilitate the triggering of conflicts by altering the stakes and balances of power? Of course, the performance of these systems would not be affected by feelings such as fear or anger, which might make it possible to save lives. But probably these systems could not adapt their response through compassion or through recognising a change in circumstances as a human being might do.

At this stage it seems difficult to oppose a change towards weapon systems with greater autonomy. We should therefore examine the legality of these weapons and their use from the viewpoint of the law of armed conflict or international humanitarian law (IHL), and firstly whether it is possible to guarantee respect for the humanitarian principles embodied in this law and under what conditions, should the need arise. In particular, but not exclusively, the foundations of this law are the Geneva Conventions and their Additional Protocols as well as the Hague Conventions and texts concerning the use of certain weapons.

This assessment should take account of rules embodied in Conventions, but also customary rules, because international customary law is independent of Convention law and consists of rules derived from general usage accepted as law. Prohibitions or restrictions may affect specific weapons or be of general application and so apply to all weapons, means or methods of warfare.

In particular, several Articles in the section devoted to methods and means of warfare in the Additional Protocol to the Geneva Conventions of 12 August 1949 relating to the victims of international armed conflicts (Protocol I) should be taken into account in an analysis of autonomous weapon systems[82].

Article 35 sets out the fundamental rules and provides that:

> "1. *In any armed conflict, the right of the Parties to the conflict to choose methods or means of warfare is not unlimited.*
>
> 2. *It is prohibited to employ weapons, projectiles and material and methods of warfare of a nature to cause superfluous injury or unnecessary suffering.*
>
> 3. *It is prohibited to employ methods or means of warfare which are intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment*".

Application of Article 36 should preclude the use of new weapons if that use would amount to a violation of international law, or possibly restrict it, depending on the conditions of use. However, the text does not specify how the process of review regarding the legality of these weapons, means or methods of warfare should be implemented[83]:

> *"In the study, development, acquisition or adoption of a new weapon, means or method of warfare, a High Contracting Party is under an obligation to determine*

[82] Adopted on 8 June 1977 by the Diplomatic Conference on the Reaffirmation and Development of International Humanitarian Law Applicable in Armed Conflicts, entering into force in 1978.

[83] ICRC, A guide to the legal review of new weapons, means and methods of warfare, 2006.

whether its employment would, in some or all circumstances, be prohibited by this Protocol or by any other rule of international law applicable to the High Contracting Party".

In addition the use of weapons, whatever their nature, in the course of an armed conflict must abide by two fundamental principles governing protection of the civilian population from the effects of hostilities:

- ⇨ **The principle of discrimination,** requiring the Parties to distinguish between the civilian population and combatants and between civilian objects and military objectives, is a fundamental rule. It is codified in Article 48 of Additional Protocol I, Articles 50, 51 and 52 respectively defining what is meant by civilians and the civilian population, what protection of the civilian population covers (defining *inter alia* what types of attack are regarded as prohibited and as indiscriminate) and the general protection of civilian objects. So the context and the environment in which an autonomous weapon system might be used are particularly important data because they will help to determine the level of capacity for discrimination that might be deemed acceptable: a counter-insurgency situation involving a mixture of combatants with the civilian population cannot be compared, in terms of parametering and the performance expected from the system, to a situation in which combatants are operating in a hostile area where it is confirmed that no non-combatants are present.
- ⇨ **The principle of proportionality** is codified by the customary rule embodied in Article 51 on protection of the civilian population and in Article 57 which deals with precautions in attack.

In the absence of applicable rules of international law, the principles of humanity and the dictates of public conscience should be considered (referring to the "Martens Clause", interpretation of which is nevertheless debatable. It is taken up again *inter alia* in the 1949 Geneva Conventions and the 1977 Additional Protocols).

It is important to make this assessment early enough in the course of the R&D process, without necessarily waiting to find out which technological solutions will be adopted, because there will be a direct impact on weapon system design itself, particularly having regard to the complexity of developing algorithms that should be capable of guaranteeing that these two principles will be respected.

Identifying responsibility in the event of violation of the rules of armed conflict law is a problem in its own right. Various responses can be postulated: designers/programmers, for example, if the incident is the result of bad parametering, the manufacturer, the person who took the decision to use the autonomous weapon system involved or even, taking the reasoning process to its conclusion, the system itself.

3.2 – How can the development and use of autonomous weapon systems be managed?

At present there is no dedicated multilateral instrument, and no specific rules, that can be used to manage the development and use of autonomous weapon systems. The way in which technological developments contributing to the design and use of these weapons should be managed is the subject of controversy. There should be in-depth discussion of the ethical and legal aspects connected with the use of such weapons, balanced according to the various uses identified and taking in the specific features of the contexts of use. In fact legal issues relating to international humanitarian law are not so much linked to the nature of these weapons as to the fact that machines are replacing human beings for committing acts of war, including the act of killing.

Thus several options may be considered in this context, ranging from no management at all to the complete prohibition of these weapons. These options include, *inter alia*:

- ⇨ **Establishing a moratorium**, which might be an interim stage. The Asilomar moratorium, one of the founding events in bioethics, is an interesting example of this type of initiative, even though in this case the issue was not the legitimacy of this work but consideration of the potential consequences of work connected with DNA recombination. The question is whether the conditions for a similar initiative applied to autonomous weapon systems are met.
- ⇨ Thus, in a report published in April 2013, the United Nations Special Rapporteur on extrajudicial, summary or arbitrary executions called upon States to establish a moratorium on the production, assembly, transfer, acquisition, deployment and use of LAR, at least until an international framework could be defined and adopted[84]. With this in view he suggested that the United Nations High Commissioner for Human Rights should create a high-level experts committee.
- ⇨ **Adoption of legally non-restrictive regulations and *ad hoc* measures**, with encouragement of a self-governance approach. A more flexible option might prove more pragmatic and easier to implement, at least at first. This approach might include *inter alia* the development of good practices and national norms and confidence-building measures, with exchanges of information on a voluntary basis[85]. The organisation of a forum for discussion is also part of the methods of encouraging these exchanges as well as harmonisation of monitoring policies and machinery[86].

Given the ethical, societal and legal issues, it is indisputably to the advantage of the principal States with an R&D programme, above all the United States, to develop a normative framework.

- ⇨ **Adaptation** of 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 (CCW)[87] is also a possibility worth exploring. This Convention is based on: *"the principle of international law that the right of the parties to an armed conflict to choose methods or means of*

---

[84] Heyns C., *Report of the Special Rapporteur on extrajudicial, summary or arbitrary executions* (A/HRC/23/47), 33rd meeting of the United Nations Human Rights Council, 9 April 2013.

[85] Anderson K., Waxman M., *Law and ethics for autonomous weapons systems* (Task force on national security and law, Hoover Institution & Stanford University), 2013.

[86] Marchant G., Allenby B., Arkin R., Barrett E., Borenstein J., Gaudet L. et al., « International governance of autonomous military robots », *Science and Technology Law Review*, 2011;12:272-315.

[87] Multilateral agreement prohibiting the use of certain conventional weapons, open for signature on 10 April 1981 and entering into force on 2 December 1983.

> *warfare is not unlimited, and on the principle that prohibits the employment in armed conflicts of weapons, projectiles and material and methods of warfare of a nature to cause superfluous injury or unnecessary suffering".*

The corpus of this Convention, which is based on humanitarian principles, defines a legal framework without stating any prohibitions or limitations in detail, because these are defined in the Protocols attached to it. This quite specific structure has been adopted to guarantee flexibility allowing it to evolve, with the adoption of new additional protocols. The scope of this legal instrument can be extended in order to take account of developments in technology and weaponry, as well as changes in warfare.

Machinery for monitoring compliance with the provisions was adopted at the third Convention Review Conferene in 2006 by a compromise decision, subsequently strengthened by several supplementary decisions. However, it is not restrictive in legal terms, which is a point of weakness.

In addition, the Convention has not always made it possible to take account of certain weapons or weapon systems, due mainly to the slowness of the process and difficulty in arriving at a consensus. Thus, for example, negotiations on the adoption of a new protocol dealing with the humanitarian impact of mines other than antipersonnel mines have come to nothing. However, new instruments have been negotiated for antipersonnel mines and cluster bombs, with the Ottawa and Oslo Conventions.

Nevertheless it should be stressed that on the other hand the Convention has made it possible to prohibit blinding laser weapons with Protocol IV. This is an unprecedented situation in arms control, but interesting to mention in the context of thoughts on autonomous weapon systems, because this prohibition deals with a weapon system that has just been developed and has not yet been used in the context of armed conflict. Thus the CCW is restating customary law, nothing more, but is also helping to establish it[88].

So the CCW is still a particularly interesting forum for discussion, making it possible to study the impact on international humanitarian law of new weapons not yet dealt with by that or some other Convention. Even if universality is till far from being achieved, the number of States Parties is steadily increasing, currently numbering 117, to which should be added 5 Signatory States.

- ⇨ **Adoption of a treaty of prohibition**. There are some who advocate prohibition pure and simple, because they fear a robotised arms race and argue that without prohibition this will become inevitable if the investments are made available and the technologies are developed. In particular an international coalition of non-governmental organisations[89] coordinated by *Human Rights Watch* (HRW) has launched a campaign for the prohibition of killer robots (*Campaign to Stop killer Robots*). In November 2012 HRW published a report on this issue, with the *Harvard Law School International Human Rights Clinic.* It concludes in particular that it would probably not be possible to design systems compliant with international humanitarian law. In addition, such an

[88] UNODA, « Promoting the universality of the Convention on Certain Conventional Weapons », UNODA Occasional Papers, 2009, n°17.

[89] These NGOs are also the ones involved in the campaign against antipersonnel mines, cluster weapons or blinding lasers.

advance would create a legal vacuum in terms of responsibility and might weaken non-legal controls with regard to murders of civilians[90].

However, this does not seem to be the most realistic option, even if it should be considered. In the current context it seems far from certain that multilateral negotiations could reach a quick conclusion. In addition, for such a legally restrictive instrument to be effective it must be possible to verify compliance with its obligations by the various States Parties and therefore to establish a verification protocol, taking into consideration the human and financial cost involved in setting up a suitable organisation. Apart from the difficulties regarding negotiations, it is also necessary to see whether developing a restrictive instrument that might quickly become obsolete or out of step with the objectives pursued is relevant.

The capability of these weapon systems to distinguish both between civilians and combatants and also between active combatants and those who are out of action or between civilians authorised to carry weapons (e.g. the police) and civilians taking part in the conflict is an essential factor in the debate. In the present state of knowledge it is difficult to assess whether advances in science and technology will make it possible to guarantee with sufficient confidence that the principles of discrimination and proportionality can be respected. The call for these weapons to be prohibited is based to a large extent on this argument. However, there is nothing to show that one day it would not be impossible to design a system that would be capable both of making this distinction but which might even prove more reliable than man. Prohibiting the development and use of these weapons now might prevent the development of weapons capable of limiting losses and collateral damage.

The questioning illustrates the fact that this is a turning point with regard to the process of developing autonomous weapon systems. On the one hand there are technological uncertainties that make it difficult at this stage to design and negotiate a relevant and suitable international framework, and on the other the questioning raised by prospects in this area must have a direct influence on R&D because the solutions supplied will have to address humanitarian and legal issues from a technological viewpoint.

3.3 – The involvement of civil society

As in the case of antipersonnel mines or cluster weapons, civil society has a place and a part to play in this debate, as shown by initiatives such as the international *Campaign to Stop Killer Robots* coalition, which brings together 47 NGOs in 22 countries[91], and the call for a total prohibition by 272 scientists, roboticians, lawyers and specialists in ethics or robotics from 37 countries, initiated by the l'*International Committe for Robots Arms Control* (ICRAC)[92],[93].

---

90 Human Rights Watch, Losing our humanity: The case against killer robots, 2012.

91 As at 1 December 2013. The Steering Committee brings together 5 international NGOs – Human Rights Watch, International Committe for Robots Arms Control (ICRAC), Nobel Women's Initiative, Pugwash Conferences on Science & World Affairs, Women's International League for Peace and Freedom – and 4 national NGOs– Article 36 (United Kingdom), Association for Aid and relief Japan, Mines Action Canada, IKV Pax Christi (Netherlands) – http://www.stopkillerrobots.org/

92 Scientists' Call – http://icrac.net/call/

93 List of signatories – http://icrac.net/wp-content/uploads/2013/10/List-of-Signatories-ICRAC-calll.pdf

3.4 – France's part in the discussions

Clarifying the terms of the debate on the issue of fully autonomous lethal robots dealing with technologies that are not yet finalised and dual-purpose, seems to be a necessity. Thus France is among the countries that have shown themselves to be particularly active in 2013, with several public contributions on this subject in international forums, and with the organisation of a dedicated seminar in September 2013.

Over thirty governments have made public statements on the question of autonomous weapon systems and related issues since the publication in April of the report by the Special Rapporteur submitted on 30 May to the United Nations Human Rights Council[94]. During the discussions that followed the submission of this report, the French representative set out the French position as follows:

> "[…], *France wishes to stress that it does not possess, and does not plan to acquire, robotised weapon systems with autonomous firing capability. Our use concept stresses that political leaders and military chiefs are entirely responsible for the decision to resort to armed force. France takes the view that the role of the human being in the decision to open fire must be maintained*"[95].

The importance of clarifying the terms of the debate on the isue of fully autonomous lethal robots, dealing with technologies that are not yet fully mastered and dual-purpose was emphasised in the statement by the French Permanent Representative to the Disarmament Conference in Geneva at the 68th session of the United Nations General Assembly (First Committee)[96].

France has also supported the European Union position, which is *inter alia* that the use of these weapons is actually governed by international humanitarian law and that therefore this issue should be debated in the relevant United Nations arms control forums. France has suggested that the CCW was the appropriate forum for the study of this issue, bringing together the necessary legal, technical and military skills[97]. France also initiated the decision to start work on autonomous lethal weapon systems taken by countries participating in this Convention in the light of the technical, legal and ethical issues. A first informal meeting of experts is to be held in Geneva in May 2014, making it possible to initiate an intergovernmental dialogue on this issue. At the end the chairman is to draft a report on the discussions and submit it to the High Contracting Parties to the Convention.

---

[94] Heyns C., *Report of the Special Rapporteur on extrajudicial, summary or arbitrary executions* (A/HRC/23/47), 33rd meeting of the United Nations Human Rights Council, 9 April 2013.

[95] Statement by Mrs Katerina Doytchinov, French Permanent Mission to the United Nations Office Geneva, 23rd Session, United Nations Human Rights Council, 30 May 2013.
http://webtv.un.org/search/clustered-id-on-executions-and-idps-contd-10th-meeting-23rd-regular-session-of-human-rights-council/2419860366001?term=10th%20meeting

[96] Statement by Mr Jean-Hughes Simon-Michel, Permanent Representative of France to the Disarmament Conference, « General Debate », First Committee, 68th Session of the United Nations General Assembly, 8 October 2013.

[97] This position was also stated by the representative of Brazil.

3.5 – Recommendations

Recommendation 9*:* France has shown that it was particularly active in relation to this issue. It seems important that it should continue its active participation in normative discussions ahead of time, while the technologies are not yet mature. Organising an international seminar in Paris based on the results of the informal meeting in May 2014 might make it possible to continue to encourage discussions on this topic.

Recommendation 10*:* At present there are no systems that are fully autonomous. Nonetheless, given the implications in terms of reserch and development, but also potential operations in the long term, the Ministry of Defence could commission a forward-looking study dealing with autonomous lethal weapon systems, focusing more specifically on technological aspects (maturity) and legal aspects.