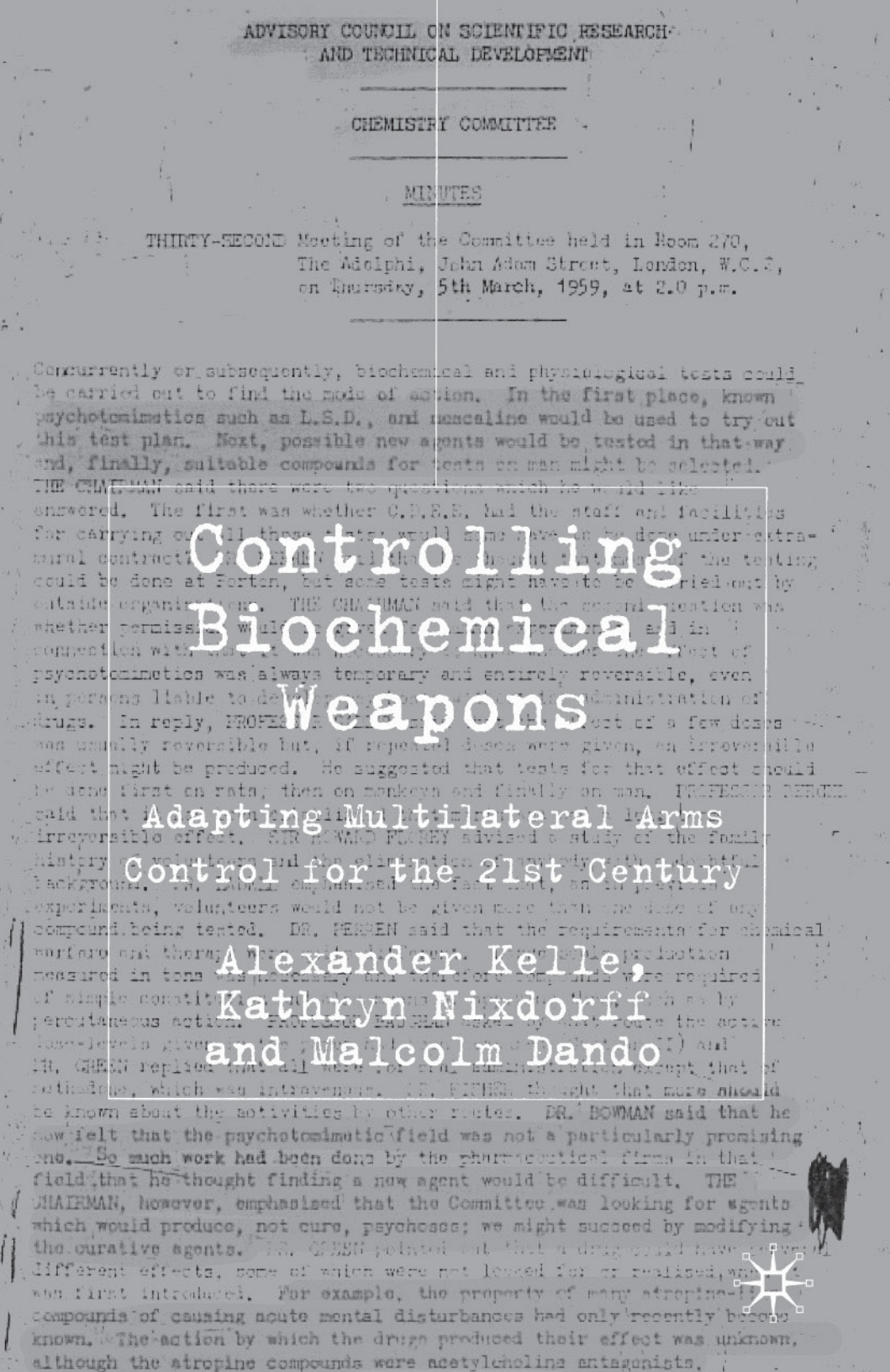

Controlling Biochemical Weapons

Adapting Multilateral Arms Control for the 21st Century

Alexander Kelle, Kathryn Nixdorff and Malcolm Dando

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Preface

This jointly authored book is concerned with the impact of the revolution in the life sciences on the arms control regimes that have been set up to prohibit chemical and biological weapons. In addressing such a truly inter-disciplinary question we have benefited greatly from exchanges with three different communities of experts: the life-scientists pursuing cutting-edge research in their respective areas of expertise for the betterment of the human condition; the diplomats in The Hague and Geneva involved in implementing the Chemical Weapons Convention and the strengthening of the Biological Weapons Convention; and the numerous colleagues in NGOs and academia with whom we were able to discuss our ideas over the years.

This book is the key outcome of a project on 'Preventive Arms Control: Analysis of the Potential for Arms Control and Verification of Biological Weapons in the Light of New Developments in Biotechnology' (Project PA 600/02), funded by the Deutsche Stiftung Friedensforschung (DSF) and directed by Kathryn Nixdorff. It would not have been possible without the support received from DSF. Malcolm Dando's contribution to this book has been made possible by a research and writing grant from the John D. and Catherine T. MacArthur Foundation on 'Building an Effective Global Prohibition Regime Against Biological Weapons' (grant no. 03–80129–00–GSS). Lastly, Alexander Kelle would like to acknowledge a MacArthur research and writing grant on 'Preventing the Malign Misuse of 21st Century Chemistry – How to Strengthen the Prohibitory Norm Against Chemical Weapons?' (grant no. 05–84295–000–GSS) whose initial phase has informed part of his contribution to this work.

As usual, the opinions expressed are ours alone, as are all remaining errors.

Alexander Kelle/Kathryn Nixdorff/Malcolm Dando
Belfast/Darmstadt/Bradford, January 2006

1
Introduction and Overview

The norm against the deliberate use of poison and disease in warfare can be traced back several hundred if not thousand years. This 'taboo' became embodied in the 20th century in three international treaties which form the basis of the two chemical and biological weapons prohibition regimes that are still today the major instruments in the fight against the spread of biological and chemical weapons proliferation and use. The three legal instruments are the 1925 Geneva Protocol, the 1972 Biological and Toxin Weapons Convention (BWC) and the 1993 Chemical Weapons Convention (CWC).

The 1925 Geneva Protocol came about as a reaction against the misuse of modern chemistry in the form of 'gas' warfare during World War I. It prohibits the use of chemical and biological – or, as in the terminology of the day, 'bacteriological' – weapons in warfare. Not prohibited are for example development and stockpiling of chemical or biological warfare agents. In addition, many states parties to the 1925 Geneva Protocol attached unilateral reservations to their ratifications, which limited the scope of the Protocol even further. During the second half of the 1960s negotiations to comprehensively prohibit chemical and biological weapons (CBW) were separated, which in turn led to the conclusion of the 1972 BWC. While the BWC was hailed as the first multilateral agreement to ban a whole class of weapons of mass destruction, the 1993 CWC has to be regarded as one of the high points of post-Cold War multilateral arms control. The CWC not only bans a category of weapons of mass destruction, but is the first such multilateral treaty that sets up a new international organization for the verification of treaty provisions.

It has become clear over the last few years, however, that the adequacy of the two prohibition regimes which aim at preventing the hostile use of chemistry and biology for offensive military or for terrorist purposes has been seriously called into question. This is due to a series of interrelated events and trends.

(1) The nerve gas attack in the Tokyo subway system in March 1995 has often been called a 'wake-up call,' refocusing attention as to the potential sources of a CBW attack. In this incident, members of the apocalyptical sect Aum Shinrikyo released the nerve agent sarin in several underground trains. The nerve gas attack killed 12 people and injured over a thousand.[1] In addition, the anthrax letters sent through the US mail system shortly after the terrorist attacks in New York and Washington, DC on 11 September 2001 seemed to confirm in a dramatic way that the question of *whether* terrorists can use biological weapons has to be answered in the affirmative and that it is now imperative to think about *when* and *how* such attacks are most likely to occur. Clearly then, terrorist groups had emerged as a new actor in chemical and biological warfare for which the existing control mechanisms were deemed inadequate.

(2) With respect to the BWC, however, the most glaring gap in the controls of this treaty was recognized long before the emergence of the bioterrorist threat. The absence of a verification system that would be able to confirm the treaty compliant behaviour of BWC states parties or, alternatively, uncover violations of the treaty initially triggered the negotiation of so-called Confidence Building Measures (CBM) at the BWC Review Conferences in 1986 and 1991. Also in 1991 the parallel process of strengthening the BWC through a legally binding international instrument, that is treaty or protocol to the BWC, was started with an exercise to first determine the technical feasibility of verification measures for the BWC. This so-called VEREX exercise was followed from 1995 to 2001 by the work of the Ad Hoc Group (AHG) of BWC states parties negotiating what came to be know as the compliance protocol. These negotiations came to an abrupt – and unsuccessful – end in July 2001 when the US government declared the approach taken by the AHG to be the wrong one, an approach to strengthening the BWC which, from the US point of view, would decrease, not increase security.[2]

(3) The chemical weapons prohibition regime is much farther developed than its BW counterpart. Yet, over the course of CWC

implementation a number of problems have come to the fore, the two most important of which relate to first the implementation of several CWC provisions ranging from adherence to CW destruction deadlines to the absence of national implementing legislation. Secondly, there seems to be an unwillingness on the part of a number of CWC states parties to keep the regime up to date with a view to adapting verification provisions to the changing face of the chemical industries worldwide. This does not bode well for agreeing upon and implementing the more far-reaching adaptations of the regime that will be required by the current revolution in the life sciences.

(4) Related to the prohibition of toxic chemicals for weapons purposes is the issue of so-called 'non-lethal' or 'less than lethal' chemical weapons. These chemical incapacitants have long been on the wish-lists of military and security forces. During recent years, however, there seems to have been an increase in interest in toxic incapacitants in the US, Russia and other countries to the point where in this context previously unknown chemical compounds, like the fentanyl-derivative used by Russian security forces to end the theatre hostage-taking in Moscow in October 2002, suddenly appeared on the scene. The development of such calmatives and other incapacitants as offensive agents on one hand creates the illusion of a more humane way of warfare in the future. On the other, the military interest in such chemical compounds threatens to undermine the prohibition of all toxic chemicals for weapons purposes. In addition, the interest in chemical incapacitants is channelling research and development and the build-up of corresponding infrastructures in a direction that might be difficult to distinguish from clearly prohibited activities under the CWC.

(5) Lastly, a series of scientific experiments and their subsequent publication suggests that the range and possibilities for malign use of biology and chemistry have greatly increased. Among the experiments of concern are the unintentional potentiation of poxviruses as a by-product of attempts to develop a mouse contraceptive, and the production of synthetic polio virus from basic chemical compounds.[3]

While these experiments of concern are mostly discussed as yet another variation of the theme of modifying or 'improving' disease-causing agents, there is a different, more fundamental change under way in the life sciences. This paradigm shift is fuelled by the decoding of the human genome and finds its expression in the establishment of new scientific subfields such as systems biology. In practical terms this

means that the current scientific and technological revolution in the life sciences changes the focus of the proliferation problem from the chemical or biological warfare agent as the object of malign manipulation to the physiological target in the human body as the object of attack. As the two prohibition regimes that have been set up to address the problem of chemical and biological weapons are agent-based (admittedly in combination with the intended use of these very agents), this revolution in the life sciences cannot but raise the question of the implications this change in our understanding of the human body at the molecular level will have for the normative structure of the two prohibition regimes currently in place.

In general terms the CBW threat is best conceived of as a chemical and biological spectrum ranging from classical lethal chemical warfare agents on one end to toxic industrial chemicals and on to mid-spectrum toxins and bioregulators, and on the other end from traditional to genetically modified biological warfare agents and on through to newly designed agents. It is to be expected that the scope and pace of scientific and technological change in the life sciences will affect all aspects of this spectrum.

There are many unknowns in the future decades. We do not know definitively what actors may use such agents, or when, where and on what scale they may be used and which particular scientific advances should be of most concern. We also do not know what the impact of defensive preparations may be, but we find it a reasonable proposition to assume that as defences improve, those with hostile intent will move from classical/traditional agents to improved (genetically modified) agents and then on to advanced (designed) agents. Should such an offence–defence BW arms race ensue, it is not too difficult to envisage severe scenarios of use: weapons of mass destruction, ethnic weapons, generational attacks and even species threatening agents.

As we will detail in subsequent chapters, the two prohibition regimes in their current shape are ill-equipped to prevent the misuse of scientific and technological advances across the spectrum of the revolution in the life sciences. The goal, then, has to be to adapt the CW and BW prohibition regimes so that they provide an adequate framework for state action and interaction to address the challenges ahead. In this context we understand regime adequacy to be composed of regime effectiveness and regime robustness, two concepts which are interrelated, but not identical. Regime effectiveness on one

hand falls broadly within the scholarly debates on international regimes.[4] In these debates there is consensus that the effectiveness of an international regime has two dimensions: first it focuses on the question whether regimes affect state behaviour in the issue area they are set up to regulate. Secondly, regime effectiveness is measured by the impact the regime has on observable data in the issue area. To use an example from the area of environmental politics, it is conceivable that states comply with emission reduction targets set for a particular greenhouse gas – which would satisfy the first aspect of regime effectiveness – and still the regime could have no impact on the ozone layer. In our area of concern the two aspects of regime effectiveness are much more closely related: if states do neither acquire nor use chemical or biological weapons then the goal of prohibiting these weapons has also been achieved – at least if the regime enjoys a universal membership.

On the other hand:

> an international regime has proven *robust* if its members continue to adhere to it and to comply with its injunctions, even after the regime has come under serious stress owing to some outside event that gives some or all of its members a strong incentive to violate, or to use their power to change, central norms and rules of the regime.[5]

To put it somewhat differently, a regime displays robustness when the actors' expectations continue to converge around the regime's normative structure, despite the occurrence of stress factors that challenge the regime. From this, the following five indicators of regime robustness can be extrapolated:[6]

- states continue their membership in the regime;
- successor states of regime members accept the 'inherited' regime membership;
- the majority of states continues to abide by regime norms and rules;
- in order to preserve the integrity of the regime, its members take action against a state which violates regime norms or rules;
- regime members display activities that aim at adapting the regime to the changed environment and thereby secure future adherence to regime norms and rules.

The latter category of activities may well include measures to enhance regime effectiveness. Although effectiveness is not regarded as a function of robustness, there exists a clear causal relationship between the two: a regime which continues to be ineffective in the sense that it does not achieve its proclaimed aims reduces members' incentives to abide by the norms and rules and thus runs the risk of losing its robustness. To strengthen the effectiveness of a regime is therefore an important tool for enhancing regime robustness.

Müller et al. identify a number of stress factors that can undermine a regime's robustness, two of which are of particular importance for our purposes: technological change and shifts in the distribution of power.[7] Many security regimes – including the CBW control regimes – exist in issue areas which are influenced heavily by technological change. Such change can work in two opposing directions: on one hand, technological developments can create new problems which are no longer adequately covered by regime rules and procedures. On the other hand, technological developments might offer new tools for problem-solving, thereby creating the impression that existing instruments have become obsolete. Regardless of its direction, technological change, if left unattended over longer periods of time, can undermine regime robustness and thus necessitate the formulation of new regime norms and rules. The likelihood that such adaptations are made is influenced to a considerable degree by the distribution of power among regime members. Shifts in power distribution can have their origins outside the regime and may well be able to transgress the regime's scope. Or such shifts can be caused by technological breakthroughs in the issue area a regime regulates, which benefits only one or a small group of states participating in the regime.

Our central concern then is with scientific and technological advances in the life sciences that can be expected to undermine the adequacy of the CW and BW prohibition regimes, if these advances are left unattended. In order to address this concern we raise four questions:

1. How are the CW and BW prohibition regimes set up to deal with scientific and technological (S&T) changes affecting the issue areas these regimes are to regulate?
2. What are the areas of concern in terms of S&T advances that might undermine the two regimes' adequacy?
3. How well equipped are the two regimes to deal with the new challenges?

4. Which adaptations of the CW and BW prohibition regimes are needed to bring them into line with the realities of 21st century life sciences?

The first of these questions will be addressed in Chapters 2 and 3, in which an in-depth analysis of the multilateral CW and BW regimes will be provided. Both regimes have their origin in the 1925 *Geneva Protocol for the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare*. However, in the late 1960s the two regimes were set on different development paths with negotiations for the two categories of weapons being separated and the Biological Weapons Convention (BWC) being successfully concluded in 1972. The CWC, in contrast was concluded only in 1993. In Chapter 2 we will provide a brief discussion of toxic chemicals and the interrelation between developments in chemistry and their misuse for weapons purposes in past CW-programmes. This misuse potential derives from the dual-use characteristics of many toxic chemicals and the equipment used to produce them. Recent changes in the structure of the chemical industry and advances in chemical process technology have reinforced this dual-use aspect. These scientific and technical issues will then be discussed in relation to the implementation of the CWC, where particular emphasis will be placed on the scope and schedules of the CWC, CW disarmament, verifying the permitted use of so-called discrete organic chemicals, transfer controls, and the CWC First Review Conference's performance in addressing S&T related issues. In a similar fashion Chapter 3 will first address biological warfare agents, their characteristics, and the emergence of the biotechnology industries in the latter quarter of the 20th century. The normative framework of the BW prohibition regime, attempts to strengthen the regime in relation to S&T advances since the mid-1970s, and in particular the efforts to negotiate a Compliance Protocol to the BWC will be discussed.

As mentioned above, we are particularly concerned about scientific and technological advances as they relate to the paradigm shift from a focus on various chemical and biological warfare agents as objects of manipulation to the increased understanding of the multitude of ways to interfere with the human body. Hence we use the different control systems in the human body that can be targeted with malicious intent as the ordering principle for our discussion of the scientific and technological advances of concern. In Chapters 4, 5 and 6 we

will discuss in detail some particularly important developments in the areas of immunology, neurosciences, and neuroendocrine-immunology that will have a bearing on the evolution of the threat spectrum we will be facing as a result of this paradigm shift.

A number of experiments involving the creation of a killer mousepox virus, the transfer of these findings to the cowpox virus, and also the potentiation of a virulence factor of vaccinia virus have made the headlines of scientific publications as experiments of concern that could be misused for nefarious purposes. What these experiments point at, however, is a dramatically increased understanding of the vulnerability of the human immune system. Picking up on this trend of placing greater emphasis on systems biology and the human immune system is the US National Institute of Health's (NIH) prioritization of immunology among the biodefence research activities it is funding. In order to provide some background for the relevance of this increased attention to immunology Chapter 4 will start with an overview of the scientific concepts underlying this field of research. This will be followed by a discussion of immune evasion strategies that microorganisms can pursue. The chapter will lastly outline some possible future threats to the immune system, for whose realization the planned NIH 'encyclopedia' of innate immunity might provide an all too useful blueprint for potential misuse.

Chapter 5 will then analyse advances in neuroscience and asks how these might be misused by somebody with malign intent. Knowledge about the working of the brain and the interaction of various neurotransmitter chemicals with their respective receptors has been accumulated over the last hundred years. What has changed through the genomics revolution, though, is first of all the much more detailed knowledge of receptor sub-type-neurotransmitter interaction, which makes it easier to target specific behaviour, which in turn could be utilized to develop more potent chemical incapacitants than have existed in the past. Secondly, there is an ever greater expectation that not only individual receptor sub-types can be identified and catalogued according to their functions, but that whole control systems responsible for specific behaviours can be elucidated at the molecular level. Thus, again there is a trend toward a systems biology approach discernible. Drawing on examples from the neurobiology of awareness, fear and cognition, but also more automatic homeostatic functions of the human body, the chapter draws comparisons of Cold War

research based on the knowledge of the 1950s and 60s with what the biotechnology revolution will enable actors with malign intent to accomplish today or in the foreseeable future in the development of biochemical agents that produce controllable effects on behaviour.

While Chapters 4 and 5 analyse developments in immunology and the neurosciences individually, Chapter 6 will add another level of complexity and bring together these two areas and the new knowledge currently being created in cutting edge research and development. Hence we will look into both the neural regulation of the immune system, including possibilities for malign manipulation, and the immune regulation of the nervous system. The chapter closes with a note of caution that the 'traditional' way of approaching the nervous system, the immune system, but also the endocrine system, as separate entities might not be the most conducive approach in order to come to terms with the misuse potential of any of these systems and the spill-over among them.

Chapter 7 will summarize the current revolution in the life sciences, thus broadening again our discussion of the selected areas presented in the preceding three chapters. This will be contrasted with the evolution of the two prohibition regimes which takes place in slow motion. This will enable us to draw together past performance of the BW and CW prohibition regimes and assess their adequacy in light of the S&T advances discussed in the preceding three chapters.

Finally, in Chapter 8, we put forward suggestions as to how the control system should be developed to match the coming threat to the CW and BW prohibition regimes. This discussion covers both national and international measures to be adopted. In the context of the latter we propose the establishment of a Framework Convention for Biochemical Controls (FCBC). Such a Convention becomes necessary as other measures either being implemented or proposed on the international level do not take into account the paradigm shift with which we are concerned. It should be understood that we accept that all of life's physiological processes will become open to (benign or malign) manipulation as the century progresses, that the threat of massive malign misuse of the biotechnology revolution is severe, and that what we are proposing is an agenda of control system development and implementation that will take some decades to perfect.

2
Science, Technology and the CW Prohibition Regime

1. Introduction

This chapter will analyse the chemical weapons (CW) prohibition regime with a view to the impact that technological characteristics of and developments related to toxic chemicals as well as developments concerning chemical processes have on the control efforts by states parties to the regime. The analysis starts from the hypothesis that recent developments in modern biotechnology, especially the utilization of combinatorial chemistry in for example the pharmaceutical industries of developed countries pose a risk to the international regime set up for prohibiting chemical warfare agents. In order to prevent the CW prohibition regime from being undermined by these – and other – recent developments, a rethinking is needed of the interrelation between the scientific and technological basis of the issue area and the political-legal regime structure brought in place to control the dangers emanating from known chemical warfare agents and other toxic chemicals and biochemicals that could be misused for warfare or terrorist attacks.

The chapter is divided into two substantive parts, the first of which will begin with a discussion of toxic chemicals and some of their characteristics that have made them attractive as chemical warfare agents. As the relationship between scientific and technological progress in chemistry and the military application of toxic chemicals has been a close one for some time, the second section of the first part will provide an outline of the development of chemistry and chemical technology on one side and its misuse in past CW-programmes during the 20th century on the other. The third section

will highlight technical issues in CW destruction, while the fourth section discusses dual-use aspects of toxic chemicals as they relate to the verifiability of the peaceful applications of toxic chemicals and the transboundary transfer of such chemicals. The first part concludes with an overview of trends in chemical industry at the turn of the century.

The second part will analyse the interrelation between scientific and technical issues on one side and the negotiations and the implementation of the Chemical Weapons Convention (CWC) on the other. To this end it will be subdivided in five sections dealing with (1) the scope and the schedules of the CWC, (2) chemical weapons disarmament, (3) the verification of the permitted uses of toxic chemicals, including unscheduled chemicals containing phosphor, sulphur or fluorine, also called discrete organic chemicals (DOCs), (4) controlling the transfer of scheduled chemicals to both state and non-state parties to the CWC and (5) the CWC Review Conference's review of scientific and technological development. This latter section will take as its point of departure the CWC's Article VIII, paragraph 22, which gives the First Review Conference a clear mandate to consider scientific and technological issues. It states that:

> [t]he Conference shall no later than one year after the expiry of the fifth and the tenth year after entry into force of this Convention, and at such other times within that time as may be decided upon, convene in special sessions to undertake reviews of the operation of this Convention. *Such reviews shall take into account any relevant scientific and technological developments.* At intervals of five years thereafter, unless otherwise decided upon, further sessions of the Conference shall be convened with the same objective. [emphasis added]

In relation to the preparation and conduct of the Review Conference, both activities of states parties and the OPCW as well as contributions from non-governmental organizations (NGOs) will be considered. The chapter will conclude with a summary of the argument, and will point out the inadequacy of the current regime structures for preventing the malign misuse of 21st century chemistry.

2. Toxic chemicals, chemical technology and military uses of chemicals for weapons purposes

2.1. Toxic chemical plus malign intent equals chemical warfare agent

The term 'chemical warfare agents' ideally would comprise all toxic chemicals that have been developed, produced, or used in a military context with the intention of utilizing its toxicity to man, animals or plants as its primary weapons characteristic. This definition excludes a considerable number of toxic chemicals used in a military environment, which serve other purposes: a case in point is rocket fuel, which is highly toxic, but whose primary purpose is the propulsion of a missile. On the other hand, this definition goes beyond that used in the Chemical Weapons Convention (CWC): according to the CWC's Article II, para. 2 only those chemicals 'which through its chemical action on life processes can cause death, temporary incapacitation or permanent harm *to humans or animals*' (emphasis added)[1] count as chemical warfare agents.

Yet, the CWC's description points to an important functional distinction of chemical warfare agents. They can be used with the intention to kill, harm permanently or incapacitate temporarily. At the same time, there is no clear-cut distinction between lethal and so-called non-lethal chemical warfare agents. Rather, 'there is a gradual increase in the probability of causing death, as the dose increases'.[2] The probability of a CW agent being lethal or non-lethal, in turn, depends on the toxicity of the agent, its mode of employment, and the target's susceptibility/responsiveness to the agent.[3]

Toxic chemicals that have been developed, produced and used as CW agents are usually subdivided into four categories: pulmonary toxicants, blood agents, vesicants or blister agents, and nerve agents.

Pulmonary toxicants: Pulmonary toxicants, sometimes referred to as lung irritants or choking gases, such as chlorine (Cl) or phosgene ($COCl_2$) were the most widely used CW agents during World War I. When inhaled, phosgene in lower doses causes a transitory irritation of the mucous membranes of the respiratory tract. With a delay of between 1 and 24 hours after exposure patients develop 'bronchiolar constriction, acute pulmonary inflamation, pulmonary edema'.[4] In addition, necrosis of bronchial and lung tissue develops. Through the destruction of lung tissue, increasing amounts of blood plasma

gather in the lungs, with their capability to provide for oxygen exchange decreasing simultaneously. Death eventually occurs through suffocation.

Blood agents: Blood agents like hydrogen cyanide (HCN) or cyanogen chloride (ClCN) were first used as chemical warfare agents in World War I. However, their high volatility made it impossible to produce them in high enough concentrations on the open battlefield, which led to their replacement by other agents. Blood agents derive their name from their interaction with enzymes responsible for oxygen uptake from the blood, or the transfer of carbon dioxide back from tissue cells to the blood. Symptoms vary according to route of poisoning and dose level. High doses of respiratory intake of hydrogen cyanide can lead to sudden unconsciousness and subsequent respiratory failure leading to death. 'Lower concentrations may produce tachypnea, restlessness, headache, and palpitations followed by seizures, coma, and death.'[5]

Vesicants: Two categories of vesicants or blistering agents have to be distinguished: one are the mustard agents, the other are a group of arsenic agents, like the so-called Lewisite. Both were extensively used during World War I, and in the case of mustard gas is still considered a major CW agent. Blistering agents are almost colourless and odourless, so that detection by the human senses is almost impossible before the onset of symptoms. Yet, depending on the route of exposure and the concentration of the agent, there can be a time lag of between 1 and 24 hours before symptoms appear. During that time tissue damage – either of the skin, mucous membranes, or the lungs – can have progressed to an extent that either long-term hospitalization is required or the victims will die from their injuries. Up to now, no specific therapy to treat mustard casualties exists.[6]

Nerve agents: As their name implies, nerve agents attack the nervous system of the human body, not other tissues. This group of agents shows by far the highest level of toxicity. Exposure can occur through the inhalation of nerve agent vapour or dermal exposure to the liquid form of the agent. These organophosphorous compounds – like tabun, sarin, soman and VX – mainly act by blocking certain neurotransmitters. The effects of exposure to nerve agents can range from nausea and vomiting, to muscular seizures, and severe damage to the central nervous system, resulting ultimately in death. The onset of symptoms can take anything from seconds to a few minutes – in the

case of nausea and vomiting after inhalational exposure – to one or more days – in the case of low-level dermal exposures producing effects in the nervous system.[7]

2.2. Chemistry and chemical warfare during the 20th century

2.2.1. Pre-World War I chemistry and CW use during the war

The use of poisons in warfare is recorded all through history in various cultural contexts.[8] However, even by the late 19th century, when more and more chemicals were produced in quantity, including toxic chemicals, their military utilization was not immediately directed towards an exploitation of their toxicity for weapons purposes. Instead it was first:

> directed towards producing better military explosives, as the nitration of natural substances ... was followed by the synthesis of nitro compounds (nitroglycerine, nitrotoluene), but not towards poisonous gases for war.[9]

Thus, it was only with the beginning of World War I when another aspect of the industrial revolution in chemistry had this effect.[10] As Robinson points out, the 'technology initially responsible' for bringing 'toxic weapons out from their prehistory' was the 'large-scale liquefaction of chlorine gas and its packaging into pressure cylinders'.[11]

It does therefore not come as a surprise that when large-scale use of chemical weapons occurred first, that it was chlorine which was used: almost 150 tons of which were released by the German army on 22 April 1915 near Ypres on the Western front. By late summer 1915 the British and by early 1916 the French forces were able to use chlorine gas in the same fashion, that is through the release from gas cylinders, where the gas was carried by the wind to the enemy troops.[12] Subsequently chlorine was replaced by more toxic chemical warfare agents, the first of which was phosgene. Yet another, from a military perspective more effective, chemical warfare agent was introduced in 1917 with the less volatile mustard 'gas', which accounted for most of the casualties due to CW use during the war. Strictly speaking, because of its lower level of volatility, sulphur mustard is not a gas, but has the military advantage of affecting the targets not only via the inhalational route, but also through the skin. Besides the