

# IMPACT OF SCIENTIFIC DEVELOPMENTS ON THE CHEMICAL WEAPONS CONVENTION

## (IUPAC Technical Report)

*Prepared for publication by#*

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# Impact of scientific developments on the Chemical Weapons Convention

## (IUPAC Technical Report)

*Abstract:* This report summarizes the findings and recommendations of an international workshop that was organized jointly by IUPAC and the Organisation for the Prohibition of Chemical Weapons (OPCW), and held in Zagreb, Croatia, from 22 to 25 April 2007. It was held to assist with preparation for the Second Review Conference of the Chemical Weapons Convention (CWC), which will commence in April 2008.

The CWC has been in force since 29 April 1997, and today 182 States have joined the Convention. The CWC aims at the total prohibition of all chemical weapons (CW) and the destruction of all CW stockpiles and production facilities by 2007. Extensions have been agreed upon and, for some CW stockpiles, the deadline is now 2012. This disarmament is subject to strict international verification by the OPCW. The CWC also prohibits the development, production, acquisition, stockpiling, and retention of CW and requires national implementation measures, including legislation, together with the international verification of chemical industry facilities. Furthermore, the CWC aims to strengthen States Parties' capacities in the field of protection against CW, and encourages international cooperation in the peaceful application of chemistry.

The CWC requires that reviews of the operation of the Convention are carried out at five-year intervals and specifies that such reviews "shall take into account any relevant scientific and technological developments", so as to ensure the continued effectiveness of the treaty and of its verification and implementation systems. This report has been prepared to assist the parties of the CWC with that review.

*Keywords:* Chemical Weapons Convention; verification; implementation; CWC; Second Review Conference.

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## INTRODUCTION

IUPAC organized an international workshop from 22 to 25 April 2007 to review advances in science and technology with regard to their impact on the Chemical Weapons Convention (CWC) in Zagreb, Croatia. This was the second of its kind: In 2002, IUPAC held the first workshop (in Bergen, Norway)

and prepared a report with findings and recommendations to the States Parties of the CWC and the OPCW. This report was well received and made a recognized contribution to the preparation by States Parties and the OPCW Technical Secretariat for the First CWC Review Conference in 2003, and it was also the major source for the OPCW Scientific Advisory Board (SAB)'s report to the First CWC Review Conference.

IUPAC and the OPCW agreed to undertake a similar project in the preparation of the Second CWC Review Conference, which is scheduled to take place in April 2008. On 16 January 2006, the OPCW Director-General, Ambassador Rogelio Pfirter, suggested such a project to the incoming President of IUPAC, Bryan Henry. In February 2006, the OPCW SAB followed up this proposal and asked IUPAC to support its preparation for the Second CWC Review Conference. A project proposal was accepted at IUPAC's Executive meeting in Dublin, and the workshop in Zagreb was set up. This report, which summarizes the results of the Zagreb workshop, will again be submitted to the States Parties and the OPCW to assist with their preparations for the Second CWC Review Conference.

Review Conferences of the CWC are convened approximately every five years. Their objective is to review the operation of the CWC, to assess the progress made with its implementation, and to provide strategic guidance for the coming years. The drafters of the CWC understood the need to review the impact of advances in science and technology on the CWC from time to time, and to organize specifically required Review Conferences to "take into account any relevant scientific and technological developments". Such advances may relate to the scope of the prohibitions set out in the CWC, affect the way it is being implemented, and create opportunities for advancing international cooperation among States Parties in areas such as protection against chemical weapons (CW) and the peaceful application of chemistry. Dialogue between the OPCW and the scientific community in evaluating scientific and technological progress also creates opportunities to advance awareness of the CWC and its requirements in the scientific, technological, and industrial communities.

Advances in chemistry, the life sciences, and enabling technologies in recent years will undoubtedly create considerable benefits for humankind—advances which could lead to improved health, a better environment, and more sustainable development. At the same time, new scientific discovery may lead to new risks, including the potential of new chemical compounds as CW. In order to fully understand the impact of these new scientific and technological developments, IUPAC organized the Zagreb workshop and prepared this report.

## **SUMMARY OF FINDINGS AND CONCLUSIONS**

The findings and recommendations of the workshop are organized into five groups: (a) technical challenges to the CWC itself; (b) technical challenges to the way the CWC is being implemented; (c) improvements in the field of chemical protection; (d) opportunities with regard to the fostering of international cooperation in the peaceful application of chemistry; and (e) requirements and opportunities with regard to raising awareness of the CWC in the scientific community, and the need for incorporating these issues into chemistry education.

### **I. Technical challenges to the CWC**

1. Science and technology continue to advance rapidly in areas that directly relate to the scientific foundations of the CWC. A key feature in this process is that chemistry and biology are converging, thus reinforcing the importance of the overlap between the prohibitions and requirements of the CWC and the Biological Weapons Convention (BWC).
2. Three aspects converge in this regard: the ability to synthesize and test large numbers of new chemical entities for biological activity; significant advances in the understanding of complex life processes in a post-genomic area; and the ability to model life processes and develop synthetic

and virtual replicas of living organisms. All this is further amplified by an increasing integration of chemistry into biology, together with engineering and the information sciences.

3. The expected benefits from these developments are significant, for example, in areas such as public health, food production, and pest control. However, there is also an increased potential for new chemicals with possible CW utility to be discovered by chance or developed by design. The advances in the life sciences may also lead to new risks in this regard. Simply expanding the Schedules will not be a practical way of dealing with this risk, given the wide range of chemical compounds relevant to the CWC that already exist or are being developed. While this risk is moderated by the fact that considerable time and effort are still required to turn a candidate novel agent into an effective weapon, it also emphasizes the need to ensure that the prohibitions in the CWC and its implementation by States Parties be comprehensive and apply to all toxic chemicals and their precursors, whether listed in the Schedules or not.
4. On the other hand, States and non-state proliferators may also opt for less effective CW (for example, by using readily available industrial chemicals). Nonproliferation efforts including measures to control access to relevant chemicals, equipment, and technologies remain important safeguards. It is important to note that effective self-governance by the scientific community must complement these control measures.
5. The risks associated with advances in science and technology would increase significantly, should dedicated CW programs be able to take advantage of them. There is, therefore, good reason to call for transparency in chemical defense programs, and to carefully assess the CWC compatibility of the development of devices that use toxic chemicals for law-enforcement purposes (including so-called “nonlethal weapons”). In order to promote transparency and build confidence, there would be advantages in considering extending the CWC’s declaration requirements to declare all toxic chemicals stockpiled by States Parties for law enforcement purposes (types, quantities, and delivery systems).
6. Technologies for the dissemination of biologically active chemicals are also continuing to evolve, driven by needs for effective drugs and pesticides. The advances in nanotechnology and particle engineering are creating new opportunities for more effective and targeted drug delivery via the respiratory system as well as other pathways. While this will improve drug delivery, it could also lead to the development of new materials based on nanoparticles that would allow for the “fine-tuning” of the desired properties of known as well as novel CW agents. For example, the delivery of chemical agents could be targeted to specific parts of the body, which may potentially enable a more effective use of smaller quantities of chemical agents.
7. At the same time, developments in the area of nanotechnology and particle engineering also create opportunities for enhanced medical countermeasures (for example, drug delivery, the development of new sensors, and diagnostics), and for the development of more effective filter materials for respirators, protective clothing, and decontaminants.
8. In short, the demands on the CWC by advances in science and technology are such that the scope of its prohibitions and the effective transformation of these prohibitions and norms into national laws and regulations, and thus the safeguarding of the comprehensive nature of the CWC—its general purpose criterion—are becoming ever more important. The OPCW should note the increasing relevance for the CWC of toxic chemicals that are not included in the Schedules, and take specific and determined action at the Second CWC Review Conference to address the effective implementation of the general purpose criterion.

## II. Technical challenges relating to the implementation of the CWC

9. The CWC is one of a number of legal instruments that deal with the control of toxic chemicals. There are clear benefits from an integrated approach to the management of chemicals, both with regard to national capacity building and cooperation between international agencies. The OPCW

should consider more fully cooperating with such mechanisms as the Strategic Approach to International Chemicals Management (SAICM), United Nations Environmental Program (UNEP)'s action to prevent international trade in toxic chemicals, and the Green Customs Initiative. There are also opportunities for strengthening national implementation capacity emanating from such programs as the European Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) initiative, effective since 1 June 2007.

10. In coming years, CWC implementation will conceivably start shifting direction: As the completion of the elimination of CW stockpiles gets closer, measures to ensure the prevention of the recurrence of CW acquisition, development, production, and stockpiling are becoming more important. Nonproliferation in the form of comprehensive national implementation including measures to ensure the comprehensive nature of the prohibition, reliable controls of transfers of scheduled chemicals, and technically sound and well-targeted international verification will need the attention and support of the OPCW and its Member States.
11. Technological innovations and advances in chemical research and development continue to make chemical manufacturing more versatile and efficient. The flexibility of the chemical industry continues to increase (e.g., the widespread use of multipurpose production equipment and the emerging industrial use of microreactors). At the same time, chemical operations are increasingly being carried out at new, nontraditional production locations (countries as well as regions), and globalization leads to an increase in the worldwide trade in chemicals. The most important development in the chemical industry has been the dispersal of sophisticated chemical production capabilities to "less developed" nations.
12. As a result, the capability of certain chemical plants in the category of "other chemical production facilities" (OCPFs) for conversion to the production of CWC-relevant chemicals is increasing and spreading. At the same time, microreactors will most likely begin to move from research application to industrial-scale use, thus changing and potentially reducing the footprint of CW production. Finally, there is production of nonscheduled chemicals that may have CW utility or could be acquired by terrorists and used as CW.
13. These trends are directly relevant to the verification system of the Convention, which was designed against a more static and deterministic concept of CW production dependent on synthetic routes involving scheduled chemicals. The OCPF verification regime is becoming more important, not only in terms of numbers of inspections per year but also with regard to a more focused selection mechanism and the delineation of its inspection aims beyond the confirmation of the absence of scheduled chemicals. It is important that the CWC does not become "frozen in time", but that it adapts to the changes in science, technology, and industrial practice.
14. The technology with regard to the destruction of CW appears to be matured. The implementation of the CWC's requirements for the destruction of CW stockpiles does not depend on significant new technological innovation or scientific discovery—existing technology can do the job. Delays are not, as a rule, caused by technology gaps but by other factors. An exception is perhaps the safe recovery and destruction of old and abandoned CW, for which a range of technologies are available but where there remains a need for innovation and new approaches.
15. Advances in science and technology can help to further enhance the technical capabilities of the OPCW verification system. Much of this will be incremental, through improved ruggedness and transportability of instruments (including miniaturization), extended databases, improved software, and the like. Of particular relevance are advances that may affect the analytical methods and instruments used in inspections, or that may contribute to further verification optimization.
16. The on-site analytical system of the OPCW, which utilizes gas chromatography/mass spectrometry (GC/MS) analysis with a dedicated analytical database and specialized software, is basically fit for purpose and meets the established logistic and operational requirements for most inspection scenarios. Gaps relate, in particular, to inspection scenarios that may involve nonscheduled chemicals, and the use of sampling and analysis in OCPF inspections.

17. With regard to off-site analysis at Designated Laboratories, advances in analytical methods and new analytical instruments are of particular relevance to trace and ultra-trace analysis, including for the analysis of biomedical samples. Some capability gaps with regard to chemical analysis exist (*inter alia*, the absence of nonscheduled chemicals, including riot control agents, from the OPCW Central Analytical Database and gaps with regard to toxin analysis and the analysis of biomedical samples). Work has only just begun at the OPCW to remedy the situation; much remains to be done to fill these verification gaps.

### III. Protection against the effects of chemical weapons

18. Advances in the life sciences, information technology, materials science, and nanotechnology all have the potential of helping States Parties to improve their protection against CW. This is important as it creates a deterrent against the use of CW. Also, enhanced international cooperation in this field can act as an incentive for some of the few remaining countries outside the CWC to join it.
19. With regard to detection devices, the conclusion from the 2002 IUPAC workshop stands that it takes much time and effort to move a new technology from laboratory to field use. Current mature technologies will continue to play a key role in the detection of CW agents during the next five years. Miniaturized versions of mature technologies capable of CW detection are now becoming commercially available. New ionization methods that enhance the ability of mass spectrometers to interrogate surfaces (liquids and solids) may greatly expand the effectiveness of inspections in the future—if these methods can be miniaturized and reduced in cost. Other trends that may lead to new detection devices include lab-on-the-chip, DNA arrays, protein arrays, and biosensors for CW agents.
20. In the field of medical countermeasures, improvements are necessary both with regard to the available treatments (e.g., antidotes that can be used against a broader range of agents), and with regard to the planning and management of medical countermeasures. Current emergency response procedures take much time, and treatment of victims is often delayed. Best practices need to be identified and applied. Training and exercises are essential to maintain the required levels of preparedness.
21. In the area of decontamination, requirements are taking account of the changing nature of such operations, which are more likely to take place in urban areas with civilians directly affected. Standard military decontamination equipment is often not effective under such conditions. There is a need for smaller and easier-to-transport decontamination equipment that requires fewer personnel to operate. Decontamination materials should be environmentally friendly and less corrosive/aggressive. Progress has been made with regard to new materials for skin decontamination. Advances in science and technology are expected to contribute to further improvements in the field of decontamination.

### IV. Opportunities in the field of international cooperation

22. The advances in the life sciences and related technological fields are expected to make significant contributions to the benefit of humankind. International cooperation and exchanges in these fields have great potential for improving public health, environmental protection, and economically sustainable development. Fostering international cooperation in these areas constitutes a desirable way of implementing Article XI of the CWC.
23. Such cooperation programs and exchanges should be pursued in recognition of the fact that they must be fully consistent with the disarmament and nonproliferation obligations of the CWC. In this context, the efforts made by the OPCW SAB and IUPAC to promote awareness of and com-

pliance with the principles and norms of the CWC by the world scientific community should be further encouraged.

24. OPCW should, in the further development of its international cooperation program, create partnerships with other international organizations that work in the field of national capacity building for chemicals management (see also paragraph 9 above).

#### **V. Awareness-raising, education, and outreach**

25. Awareness in the scientific and technological communities in all countries about the CWC and its norms, prohibitions, and implementation requirements remains poor. This calls for increased outreach by States Parties and the OPCW; at the same time, it also proves the need for further efforts to incorporate ethical norms and knowledge about the CWC and the dual-use nature of advances in science and technology into chemistry education. Cooperation with UNESCO (United Nations Educational, Scientific and Cultural Organization) could be explored in the development and adoption of ethical codes. IUPAC has started a project that is addressing these needs. However, it remains important that States Parties and the OPCW continue to reach out to the scientific community, promote the adoption of codes of conduct that take account of the CWC (either in the form of new codes or by adding CWC-related elements to existing codes), and maintain a dialogue with the scientific community and civil society. The requirements and norms of the CWC should become a regular part, at an early stage, of the education of every student of chemistry and chemical engineering.

#### **VI. Proposals to the OPCW**

The development of new nonscheduled toxic chemicals, other scientific and technological advances, and the difficulties of monitoring and controlling these chemicals to prevent their use in ways prohibited by the CWC pose significant challenges to the CWC. These need to be fully addressed by both the States Parties and the OPCW as a whole. The following measures should be considered by the Second CWC Review Conference:

- Additional efforts to ensure full and effective national implementation of the CWC, especially with regard to the implementation of the General Purpose Criterion.
- Agreement on the need for the declaration of toxic chemicals held by States Parties for law enforcement purposes (types, quantities and delivery systems).
- Further enhancement of OCPF verification (increase in the number of such inspections, improved selection mechanism, additional information available to the Technical Secretariat on the nature of activities and equipment at a site, longer inspection times, regular use of sampling and analysis).
- Further development of OPCW analytical capabilities to improve portability, reduce equipment weight and size, shorten the time needed to become operational, and reduce the time and cost to analyze samples.
- Establishment of a capability of the OPCW to analyze toxins and biomedical samples, and inclusion of relevant nonscheduled chemicals into the OPCW analytical database. The establishment of a separate and expanded database for investigations of alleged use should also be considered.
- Training of chemists, particularly in the developing world, in the use of these analytical methods and equipment so that national implementation of the CWC can be improved.
- Strengthening of linkages and collaboration with other international treaties and mechanisms related to managing chemicals and minimizing their adverse impacts (e.g., BTWC, SAICM, UNEP illegal trade action, Green Customs, REACH).

- Taking advantage of the opportunities provided by the advances in science and technology for the fostering of international cooperation in the peaceful uses of chemistry, as well as for the strengthening of capacities with regard to the protection against CW.
- Reaching out to the scientific community and to all those working with chemicals, and promoting the adoption of codes of conduct to ensure full CWC compliance as well as the incorporation of the norms and requirements of the CWC into chemistry education.

## THE WORKSHOP

IUPAC and the OPCW organized a Workshop entitled Impact of Scientific Developments on the CWC in Zagreb, Croatia, from 22 to 25 April 2007. Financial support was provided by the Organisation for the Prohibition of Chemical Weapons (OPCW), the U.S. National Academies, IUPAC, several Croatian Ministries, the Faculty of Chemical Engineering and Technology of Zagreb University, and the Croatian Chemical and Chemical Engineering Societies. The Workshop was held under the auspices of the Zagreb city government.

There were 68 participants from 29 countries\*, coming from government, chemical industry, chemical research institutes, and universities. Seventeen participants from 11 countries were representatives of governments from government departments, National Authorities, and laboratories. Eleven participants were members of the OPCW SAB. Fourteen participants had attended the previous workshop in Bergen, Norway in 2002. Technical input was also provided by the OPCW in the form of presentations and posters.

### A. Presentations, posters, and discussions

There were six plenary sessions and one final wrap-up plenary, as follows:

- **Overview and background:** The first three speakers in this session outlined the background for the workshop, set out its objectives and provided background information on the CWC implementation process. To provide a basis for the subsequent discussions, they also elaborated on the evolution of the CWC verification regime, with particular emphasis on verification of nonproduction of CW in the chemical industry. The final two speakers provided an overview on trends in the chemical industry and future challenges to the CWC regime.
- **Synthesis:** This session provided an overview on advances in drug discovery and development, on the emergence of synthetic biology and DNA synthesis, and on issues related to post-genomic developments including in such areas as bioinformatics.
- **Production technology:** This session looked at how fine-chemicals manufacturing was evolving in a number of countries in Eastern Europe, Asia, and South America, using the BRIC (Brazil, Russia, India, and China) countries as a particular example of these current trends. It also provided an overview of the state of the art in catalysis and biocatalysis, the use and protection against toxic (industrial) gases, and the evolving application of microreactors in chemicals manufacturing.
- **Nanotechnology and aerosol drug delivery:** This plenary session reviewed two areas of science and technology that are of importance for the targeted delivery of drugs but could also be relevant for the potential emergence of new delivery means for CW, as well as for the development of more effective means of protection against them.

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\*Participants came from Argentina, Australia, Belgium, Brazil, Canada, Croatia, Czech Republic, Finland, France, Germany, India, Iran, Japan, Nigeria, The Netherlands, Norway, Poland, Romania, Russian Federation, Singapore, Slovenia, South Africa, South Korea, Spain, Switzerland, Turkey, United Kingdom, United States, and Ukraine.

- **Analysis:** The session reviewed the current state of the art with regard to the analysis of environmental (chemical) as well as biomedical samples. These trends were discussed in the context of the specific verification requirements of the CWC. The session also looked at the current trends with regard to CW agent detectors for field use.
- **Medical countermeasures and decontamination:** This session heard an overview on current trends in medical countermeasures, received background on the synthesis, use, and interaction of certain new potential antidotes for the treatment of nerve-agent poisoning, and discussed the state of the art with regard to decontamination.

A poster session provided background information on the way in which the OPCW is implementing CWC provisions in the areas of assistance and protection as well as international cooperation in the field of peaceful uses of chemistry. Furthermore, technical issues related to the destruction of CW and to countermeasures against CW were presented, as was information on an IUPAC awareness-raising and education project.

The workshop was organized into four parallel break-out groups which prepared suggestions for findings and recommendations. These were presented and discussed at plenary sessions, and consolidated after the workshop into this present report.

## B. Detailed discussions

### I. Technical challenges to the CWC

1. Advances in science and technology can affect the CWC in a variety of ways: The discovery of new biologically active chemicals and of new carriers that can transport such chemicals to specific parts of the body needs to be reviewed in the light of the scope of the prohibitions of the CWC, technological advances may affect the way it is being implemented (including with regard to CW destruction and verification), and they may create opportunities for advancing international cooperation between States Parties in such areas as protection against CW and enhanced international cooperation in the peaceful application of chemistry. This section looks at the first of these issues.
2. The pace of progress in the life sciences and related enabling technologies has increased considerably in recent years. So has the complexity of the knowledge gained about the molecular mechanisms of life's fundamental processes. Chemistry and biology are overlapping scientific fields in the discovery and development of new drugs. Starting with the selection of a disease and a related drug target, large numbers of chemical compounds are being synthesized and screened in order to identify suitable lead compounds. This process is being facilitated as well as complemented by advances in molecular genetics and the mapping of the DNA of humans as well as microorganisms, the use of computer-aided design of new lead compounds, and at the same time by the availability of combinatorial synthesis methods and automated high-throughput screening procedures. This involves the automated testing of large numbers of compounds against a large number of targets where, typically, several thousand compounds can be tested in 30–50 biochemical tests at the same time.
3. In addition, there is interest in furthering the understanding of the action of naturally occurring toxic chemicals (toxins). Studies involve the isolation and characterization of such molecules from natural reservoirs, the development of modifications and derivatives of such chemicals, and studies to mimic their action—all the way to the synthesis and study of what may be called “artificial toxins”. As a consequence, the future toxin spectrum will be more complex and more unpredictable than that of the presently known chemical and biological agents.
4. Developments in synthetic biology (the design and assemblage of interacting genes into circuits in order to direct cells to perform new tasks) promise further advances that are relevant for the discovery of new drugs. And finally, systems biology (in a post-genomic area) is beginning to

shape our understanding of the complex interactions of physiological systems. It is extremely difficult to assess the consequences of targeting these systems with chemicals designed to modulate a particular function in one of the systems.

5. One consequence of these advances is that the capability to synthesize and screen chemical compounds for biological activity that may be developed for CW purposes is also increasing. Furthermore, a large number of biologically active chemicals are being synthesized and tested in legitimate research and development—among them will inevitably be toxic chemicals some of which may have other properties that could make them candidate CW agents.
6. It will not be practical to approach this increase in the number of known toxic chemicals with potential CW utility through an expansion of the Schedules. On the one hand, the number of chemical compounds that are so being synthesized and screened is huge. On the other hand, the amounts synthesized are such that the application of the industry verification system (for which the Schedules have been designed) would not be triggered. Also, these developments have to be assessed in context: there are already a very large number of toxic chemicals that have not been included into the Schedules because their inclusion would not be practical.
7. As for the prohibitions of the CWC, any such new chemical will fall under the provisions of the CWC should it ever be used for CW purposes. This is the consequence of the definition of chemical weapons, which covers all toxic chemicals and their precursors (irrespective of their origin or method of production) unless they are intended for legitimate purposes, and as long as their types and quantities are consistent with these legitimate purposes (“General Purpose Criterion”). Implementing this criterion through appropriate legislation and enforcement measures is clearly a challenge for States Parties. It is also a challenge for the verification system of the CWC, which is to a large degree driven by the Schedules.
8. On the other hand, despite this dramatic increase in knowledge and in the number of chemicals that could have CW utility given their toxicological and chemical profile, the risk to the object and purpose of the CWC posed by these scientific advances may not have increased as much as one might fear. To use a new toxic compound as an effective CW requires a number of developments before it can successfully be used. However, the risks from such novel toxic chemicals should not be ignored.
9. On the other hand, States as well as non-state proliferators may also opt for less effective CW (using well-known agents or readily available industrial materials). Nonproliferation efforts including verification and national implementation measures, *inter alia* to control access to relevant chemicals, equipment, and technologies, remain important safeguards. At the same time, effective self-governance by the scientific community must complement these control measures.
10. The risks associated with these advances in science and technology would increase significantly, were there dedicated CW programs that would take advantage of them. There is therefore good reason to call for transparency in chemical defense programs, and the recent progress made by the OPCW with regard to the annual submission of information on national protective programs will help in this regard.
11. Advances in nanotechnology and aerosol drug delivery, driven by the needs of such sectors as the pharmaceutical or pesticide industries, are also significant. They may be exploited for more effective and targeted delivery methods for toxic chemicals. Many of the considerations that promote the design of particles for effective and targeted drug delivery via the respiratory system would equally be applicable in a program to improve the dispersion of a CW agent in the atmosphere. An example is the use of large porous aerosol particles that allow the delivery of drugs into the deep regions of the lungs to promote absorption in the alveolar region—if used for CW purposes this could increase the systemic toxicity of a given agent. The spray-drying equipment needed to create such particles is relatively cheap and widely available—yet the optimization of a well-engineered particle requires considerable time and skill. The technology can be combined with nanotechnology to deliver nanoparticle aggregates that will disperse in the body once ad-

- sorbed. Furthermore, particle design (e.g., multifunctional polymeric design) can be used to improve drug targeting and selective delivery.
12. In a more general sense, advances in nanotechnology can be used to engineer/design biologically active systems and “smart” materials that respond to specific stimuli and deliver active ingredients to specific targets in the body. Nanotechnology may allow the development of capsules for safe enclosure and targeted delivery of biologically active chemicals. It may enhance the use of active groups for bonding to specific targets in organs or cells. It may provide new means of facilitating entry into the body or cells, in particular in the brain, for selective reaction with specific gene patterns or proteins, or for overcoming the immune reaction of the target organism. These developments promise significant benefits in the form of new medicines but at the same time could be used in a program aimed at developing more effective CW. It should also be noted that at the nanolevel, the boundaries between biological, chemical and physical action become blurred. Therefore, it may be desirable for the States Parties to clarify and affirm that the CWC’s reference to toxic chemicals and their chemical action on life processes includes the action by nanotechnology-enabled microscopic agents.
  13. At the same time, nanotechnology enables faster, cheaper, more sensitive, and more selective sensors, as well as better filtering and decontamination methods. Therefore, it is expected to contribute to improvements of the means of protection against CW.
  14. In the absence of dedicated State programs to develop and produce CW, which are forbidden to the parties of the CWC, the risk to the object and purpose of the CWC emanating from the advances in science and technology described above is moderate at this stage. Transparency in chemical defense programs of States Parties through regular submission of information on them to the OPCW, as required under Article X of the CWC, provides reassurances that such offensive programs have not been initiated.
  15. However, the risks emanating from these advances in science and technology cannot be ignored as long as there remain States outside the CWC regime that may have active CW programs. These advances may also attract the attention of non-state actors including terrorists who may have an interest in acquiring a CW capability. On the other hand, when compared to other risk factors, including the presence of significant amounts of toxic chemicals in industry and in transportation systems, the advances in science and technology described above do not seem to change the situation significantly, at least not for the time being. They should be monitored and reviewed, and the increasing pace of progress in chemistry, the life sciences, and enabling technologies may well call for more frequent reviews than provided for by the five-year cycle of CWC Review Conferences.
  16. Many of the chemicals that are being synthesized and screened as part of the drug discovery efforts described above will have incapacitating properties that could make them suitable as so-called “nonlethal” agents. They interact with the central nervous system or other physiological systems, and one of their “design criteria” is that the margin between their lethal and incapacitating doses is wider than for previously employed CW agents such as nerve or blister agents. Some may argue that such compounds may have utility for use in law enforcement, a specific use of toxic chemicals that is not prohibited by the CWC. Efforts are reportedly underway in some States Parties to develop weapons with nonlethal properties for use in law enforcement situations. But such weapons may also be thought to have utility in counter-terrorism or urban warfare situations.
  17. If these developments were to continue unchecked (with regard to the possible use of toxic chemicals for these purposes), there is a serious danger that the prohibitions of the CWC would be undermined. Activities to develop “nonlethal” weapons based on incapacitating agents would not easily be distinguishable from aspects of an offensive CW program: The agents would actually be weaponized, and the considerations with regard to the time between the discovery of a new toxic chemical that might be a candidate novel CW agent and its emergence as a CW may no longer apply.

18. Therefore, a clear need exists for States Parties of the CWC to address these risks to the object and purpose of the CWC and to agree on the CWC compatibility (or incompatibility) of endeavors to develop and field “nonlethal” weapons that utilize toxic (e.g., incapacitating) chemicals for law enforcement purposes. Should the development and acquisition of such weapons be accepted, there would clearly be a need (as is the case of riot control agents) to agree on declaration provisions for such weapons (types, quantities, and delivery systems).

## II. Technical challenges to the implementation of the CWC

19. Technical challenges to the implementation of the CWC relate to a range of issues:
- the effectiveness of the verification system in the light of changes in the chemical industry (new technologies, equipment, and chemicals as well as structural changes in the manufacturing of and trade with chemicals);
  - technical challenges regarding the destruction of CW, including old and abandoned CW; and
  - advances in science and technology that may enhance the technical capacity of the CWC verification system or help in reducing verification costs.

### *Changes in the chemical industry*

20. The chemical industry continues to change under the impact of globalization and market pressures. As a result of differences in market growths and labor costs, industrial production of chemicals is migrating from Western Europe to Eastern Europe and Asia, from North America to South America and Asia, as well as from developed to developing countries. Industrial societies are becoming service societies, supported by trends in information and communications technologies, demographics, and regulation. There is limited growth potential in the North American Free Trade Agreement (NAFTA) countries, Europe, and Japan as more and more consumer industries migrate to low-cost countries. A number of these countries, including Brazil/Russia/India/China (the BRIC countries), are likely to become major players in the fine chemicals market, whilst the Middle East is likely to take the lead in the field of basic petrochemicals.
21. These trends had already been observed in the preparation of the First CWC Review Conference. They affect the industry verification system of the CWC in several ways:
- the emergence of “world chemical plants” where a single plant supplies a significant part of the total world demand of a certain chemical, which leads to increased transfers of chemicals and may make certain verification principles more difficult to apply;
  - a high degree of standardization, which can assist verification and increase transparency in industry operations;
  - an increase in trade volumes for chemicals, which poses a challenge to the CWC declaration and data monitoring system regarding aggregate national data of exports and imports of scheduled chemicals (a particular issue is the differences between national regulations to account for mixtures containing scheduled chemicals);
  - chemical production in countries which had no chemical industry in the past, which creates challenges for national CWC implementation, for the support by OPCW to States Parties in the identification of declarable industrial facilities, and for the geographical spread of industry verification activities;
  - sourcing, production, and trade, which are global and make verification by data monitoring more complex;
  - more specialist production in traditional chemicals-producing countries, with facilities that may have chemical, technological, and equipment features that make them highly relevant from a verification perspective;

- new technological advances used in chemicals production create new challenges to the verification system and continue changing the footprint of CWC-relevant facilities (e.g., new catalysts, new types of equipment and technology including microreactors, biotechnology in chemicals manufacturing, nanotechnology); and
  - new international initiatives such as SAICM and the UNEP action to prevent illegal trade in toxic chemicals as well as new regulatory mechanisms for chemicals and chemical manufacturers (e.g., REACH in Europe) create pressures on the industry, but also new opportunities for international cooperation as well as integrated national capacity building. These initiatives also contribute to efforts to maintain a level playing field for the industry worldwide, and create additional transparency that may ease verification.
22. The chemical industry has been implementing its Responsible Care<sup>®</sup> program in the International Council of Chemical Associations (ICCA) member countries to improve product stewardship, workers' safety and health, plant safety, and transport safety. In the industry's own words: "Responsible Care promotes co-operation with governments and organizations in the development and implementation of effective regulations and standards, and helps companies meet or exceed these requirements" (for more information, see [1]). These self-regulatory measures provide transparency, facilitate verification, and provide additional safeguards with respect to the security of chemical plants.
  23. The technological advances in the manufacturing of chemicals are significant. The synthesis of new chemicals and the evolution of chemical production technology are both relevant to the CWC. In the future, traditional chemical operations based on oil- or gas-based feedstocks will be combined with a renewable resource base utilizing farming and bioprocessing technologies. Process efficiency is becoming ever more important. It helps to minimize the environmental impact of chemicals manufacturing and to better utilize renewable feedstocks. It also makes it possible to apply energy-efficient processes with (near)-100 % efficiency in the utilization of raw materials leading to drastically reduced generation of unwanted by-products and waste. Catalysis increases selectivity (chemo-, regio-, stereoselective processes) and improves the economy of reactions using standard equipment.
  24. One area where much progress is being made is catalysis and biocatalysis. Catalysis is important for the efficient production of mass as well as fine chemicals. It can also be utilized both for the production and the destruction of CW. Some 85 % of the industrial chemical processes are catalytic in nature (of which 85 % are using heterogeneous catalysts, 17 % homogeneous, and 3 % biocatalysts). Nanotechnology offers new avenues for the design of catalysts which will increase reactivity, selectivity, and efficiency of chemical processes. An example is the development of catalytic support for chemical synthesis. At the same time, photocatalytic effects offer opportunities for the degradation of known CW agents, which may be useful for protective purposes (decontamination, water purification). In general, it has been argued that catalysis is the most important of the cross-sectional technologies in the chemical, refining, and polymer industries, as well as in emission control. With regard to the CWC, advances in catalysis enhance the efficiency, selectivity, and economy with which biologically active chemicals of potential CWC relevance can be produced. At the same time, they offer new solutions with regard to the destruction of and protection against CW agents.
  25. The increased use of multipurpose production equipment and technologies was already observed five years ago, when IUPAC reviewed advances in science and technology in preparation of the First CWC Review Conference. The use of multipurpose (batch) production equipment has become commonplace in certain branches of the industry. It is used to optimize the manufacturing of medicines, pesticides, fine chemicals, and other high-value products, and to synchronize their production with changing market demands. Furthermore, the custom manufacturing of fine chemicals (intermediates, additives, etc.) has further contributed to the spread of small-to-medium scale highly versatile producers in the chemical industry. These producers have the technological

capability and know-how as well as access to a chemical raw material base to manufacture more or less any chemical on demand. The conclusion from IUPAC's study in 2002 stands—there is a need to review the verification regime for OCPF to ensure that it is effective, as it is in such OCPF plant sites where many of these multipurpose plants are located.

26. Another trend identified five years ago relates to the emerging use of microreactors in industrial production. One of the driving factors is safety: Chemicals that are otherwise hazardous to manufacture, handle, or store can be produced on-site when needed. Other important factors include the smaller amounts of reaction by-products, better kinetic data for reaction optimization, and lower capital costs. Microreactors achieve advantageously high surface-to-volume ratios, short retention times of the reactants, and continuous and very precise control of the reaction parameters. Many chemical reactions have now been demonstrated to show improved reactivity, product yield, and selectivity when performed in microreactors compared to those generated using conventional laboratory equipment. Furthermore, many of the traditional problems associated with scaling-up production from laboratory to industrial-scale volumes can be avoided by what is called “numbering-up” (i.e., running large numbers of microreactors in parallel).
27. Assessed in the context of the CWC, microreactors pose several issues. From a verification perspective, many of the traditional features associated with the manufacturing of volatile highly toxic (or corrosive) materials (high stacks, heavy-duty ventilation and scrubbing equipment, and the like) may lose their relevance, as they may not be needed in a production line using microreactors. Combined with combinatorial techniques of drug discovery, the use of microreactors can significantly shorten the time required to synthesize new toxic chemicals for testing and development purposes. Furthermore, the times needed to scale up production of a novel agent from the development phase to full-scale production can be significantly shortened by “numbering-up”. Also, certain reaction steps that in traditional reaction environments pose significant challenges (e.g., because of the corrosiveness of the reaction medium) or extreme exothermicity can more easily be controlled in microreactors. The inherent versatility and adaptability of chemical manufacturing is increasing as a result, and thereby (at least in theory and from a merely technological point of view) the ability of certain chemical operations to be converted for the manufacturing of CW agents. It should also be noted that microreactors have become an interesting research tool and are increasingly used in universities and applied research around the world. As for industrial manufacturing, they appear to be slowly but steadily becoming a true alternative to conventional batch reactors for specific types of reactions (e.g., highly exothermic, or requiring a specific catalyst that does not work well in a bulk reactor). At the same time, it appears that the introduction of microreactors into industrial-scale production is progressing more slowly and selectively than originally predicted by some proponents of microreactors. It remains to be seen to what extent microreactors will be used for industrial-scale production. The developments should be further monitored, but in the meantime the effect on the CWC regime is largely in the area of development of new chemicals, not the industrial production of relevant (scheduled or nonscheduled discrete organic) chemicals.
28. These trends in chemical production technology progress alongside developments, at present predominantly in the research and development areas, toward a more frequent use of biological processes for chemicals manufacturing (e.g., the use of transgenic organisms to manufacture materials that are difficult or costly to extract from natural resources, and where traditional chemical synthesis is also technically difficult and costly). These technological advances are driven by the needs of a multitude of industries and users, and are spreading at a global scale.
29. The CWC's response to these evolving capabilities in the manufacturing of toxic chemicals with CWC relevance is in the comprehensive nature of its prohibitions—its General Purpose Criterion—implemented by States Parties. From a verification perspective, the OCPF verification regime becomes more important as a safeguard against regime break-out. The OCPF regime was included in the CWC industry verification system at the end of the negotiations, and it was de-

liberately set up as an evolutionary, dynamic system that could take account of experiences gathered in the implementation process, and adapt to new requirements emanating from science and technology as well as industrial practice. The regime needs to evolve further (in terms of how many inspections are being conducted, how plant sites are selected for inspection, how the inspection aims are defined in particular with regard to chemicals that are not listed in any of the Schedules, and how biological manufacturing processes are covered by the regime) if it is to provide reliable assurances of compliance with the CWC in the future. Many technological advances in the chemical industry are of a dual-use nature and affect directly the intrinsic capability that would be needed if chemicals manufacturing was diverted to CW purposes. All of these developments underline the importance of effective implementation of the General Purpose Criterion by States Parties, and because change in the industry is taking effect fast, attention needs to be given to how best to adapt the chemical industry verification system in the future.

#### *Destruction of chemical weapons*

30. Technologies for the destruction of stockpile CW have matured to a point, and timelines for the completion of CW destruction operations are such, that there is little point in reviewing emerging technology options for these destruction operations. Although there remain CW destruction facilities that have yet to be commissioned, the technology choices are well known and assessed [2,3]. Issues that may influence outstanding decisions on technology choices are largely in the legal, policy, regulatory, public awareness/education, and economic domains.
31. On the other hand, there remains an interest in technologies that are suitable for the destruction of non-stockpile CW and CW remnants (old and abandoned CW), partly driven by anticipated future recovery operations of such items, partly also because of the characteristics of some of the smaller stockpiles that are awaiting destruction. The key difference is that while stockpile CW, as a rule, are in good and consistent condition, non-stockpile items usually are not. For stockpile CW, it is therefore possible to design disassembly lines to separate the agents from the munitions or containers, as well as from any explosive fills, and to subsequently treat these material streams separately. Explosive materials are burned off, contaminated metal parts are burned out and subsequently mutilated, and the agent fills are destroyed by incineration or chemical neutralization followed by further treatment processes of the reaction masses such as incineration, stabilization in bitumen, or biodegradation.
32. Old and abandoned CW, on the other hand, are usually found in conditions that pose additional complications: lack of uniformity, corrosion/deterioration of munitions/shells/containers as the result of environmental degradation, instability of fused weapons which could lead to unexpected explosions, and agent degradation that are incompatible with a standardized disassembly line typically used for stockpile materials. Consequently, technologies for the destruction of non-stockpile CW have taken a somewhat different route from the destruction of stockpile CW, and are usually “total solutions”: They access the agent, destroy the energetics and agents, and decontaminate the munitions bodies without an initial process step that separates agent from energetics and munitions bodies. Nor is there a separate agent neutralization step. Solutions include technologies such as “cold” detonations of the munitions/devices (using an explosive charge) inside an explosive-containment structure combined with off-gas treatment and “hot” explosion of old chemical munitions/containers in, for example, a rotary or static kiln combined with an off-gas treatment system. Other options are acid digestion of whole munitions, bulk vitrification and destruction in firing pools, as well as a number of processes to destroy bulk agent (neutralization with addition of bitumen, incineration, destruction in an electrical furnace, biological processes, electrochemical oxidation, photocatalysis, and destruction in a plasma).
33. The workshop did not discuss issues related to the recovery and destruction of sea-dumped CW. No operations of such kind are currently under way at any significant scale. Satisfactory (safe,

economical, and efficient) technological approaches to the recovery and destruction of these CW, however, have yet to be developed.

34. In summary, it appears that advances in science and technology have an incremental impact on the availability of efficient, safe, reliable, and economically viable technologies for the destruction of CW, including their remnants in the environment. The technology in the field has matured to a stage where the implementation of the CWC's requirements does not depend on new technological innovation or scientific discovery—existing technology can do the job well. Delays in the elimination of CW stockpiles are not, as a rule, caused by technology gaps, but other factors.

#### *Verification*

35. Advances in science and technology can be utilized to improve the effectiveness, efficiency, and selectivity of methods and techniques used to verify the CWC, and to reduce the logistical burden associated with the transportation, storage, and use of the inspection equipment. OPCW inspection teams employ a wide range of inspection equipment, ranging from communications, IT and other administrative equipment to location finding equipment, photographic equipment, conventional and fiber-optical seals, weighing and measuring devices, health and safety equipment (including CW agent detectors and individual protective equipment), medical equipment, and a range of analytical equipment including instruments for on-site chemical analysis and for non-destructive interrogation of munitions and containers.
36. The workshop did not seek to address technological advances in all these areas. There was no need to do so: The OPCW Technical Secretariat is constantly analyzing its requirements and the trends on the instruments market so as to ensure that any gaps in its equipment suite can be filled or the cost-effectiveness, ruggedness, and reliability of inspection equipment improved. The workshop therefore focused on trends related to equipment and methods used for chemical analysis for verification purposes.
37. The OPCW has established a system for the collection, processing, and analysis of process and environmental (chemical) samples that is based on:
- validated sample collection, handling, splitting, and processing procedures including chain-of-custody procedures for a variety of sample matrices (surface-wipe samples, bulk chemicals, organic liquids, water-based samples, soil samples, solid samples);
  - a validated spectral databank for GC/MS (as well as certain other) analytical data, covering several thousand scheduled chemicals (the OPCW Central Analytical Database or "OCAD");
  - a specifically developed software package (OPCW Dual Mode Software, ODMS) that allows to run an instrument in "blinded" mode, thereby preventing the analyst from having access to the full spectral run data but displaying data of any chemical from the target library (the OCAD) that was detected in the sample (this "blinded" mode of the software is used when so requested by an inspected State Party to protect confidential information that may be contained in a sample);
  - the use of portable (bench-top) GC/MS for on-site (field) analysis; and
  - a network of Designated Laboratories for off-site analysis of authentic verification samples, whose performance is tested regularly in proficiency tests. These laboratories must maintain accreditation under ISO standard 17025.
38. The on-site part of the system has been tested on various occasions, in training, exercises, and actual inspections. It has been used routinely at CW destruction sites. Since the second half of 2006, its use in routine inspections of chemical industry facilities (Schedule 2 facilities) has been piloted. Current experience is that the system is working well. The logistics are manageable, the set-up times correspond to standard inspection requirements (the system is ready to receive a sample for analysis after approximately three hours), and the analysis itself is reliable and reasonably fast.

39. The number of samples that can be analyzed during a given inspection, on the other hand, is fairly limited. This is largely because of the requirements related to sample preparation. The logistical burden associated with sample processing on-site could also be reduced. The adopted procedures depend on solvent extraction followed by solvent concentration through evaporation (water and organic solvent). Evaporation carries a certain risk of losing some of the analyte and, more importantly, in the case of water is time-consuming and energy-intensive. Supplementary sample preparation techniques such as solid-phase extraction have been proposed. These should be tested, and if found suitable validated and introduced for on-site use by OPCW inspection teams.
40. Another analytical method that has been identified is the possible use of liquid chromatography coupled with mass spectrometry (LC/MS), which allows direct analysis of aqueous matrices and underivatized analytes. The potential use of LC/MS in on-site inspections should be evaluated. Another potential complement to GC/MS analysis is infrared spectrometry—a technique already approved by the OPCW as a possible on-site inspection method but currently not in use owing to the additional logistical burden its use would cause compared to the limited benefits that this additional method would contribute to an inspection.
41. At the same time, the number and variety of analytical instruments and techniques for on-site use by inspection teams should be kept small, given the ramifications that an “inflation” of on-site analytical instruments and techniques would have with regard to inspector qualification/skill levels that can realistically be maintained, resulting training needs, and additional requirements with regard to database development, validation of procedures and spectral data, quality control, inspection logistics, and inspection costs.
42. The OPCW has over the past number of years established a fully validated and quality-controlled central analytical database (OCAD) for verification purposes. The database holds GC/MS data, as well as some IR and NMR spectra, of scheduled chemicals. The vast majority are GC/MS data (i.e., mass spectra and GC retention indices). OCAD is today a powerful specialized database that provides valuable analytical data for most OPCW inspection scenarios. For routine purposes, it meets most requirements. It does not, however, contain data for unscheduled chemicals (such as riot control agents, nonscheduled degradation products of scheduled chemicals, toxic industrial chemicals, toxins, “mid-spectrum agents” or toxic chemicals with utility as “nonlethal” weapons). This limits its utility under certain inspection scenarios (in particular with regard to investigations of alleged CW use, allegations of the use of riot control agents as a method of warfare, and certain scenarios in challenge inspection). Therefore, an extended version of the OCAD also containing unscheduled chemicals for use in investigations of alleged as well as challenge inspections should be prepared.
43. With regard to off-site analysis, the OPCW has established a network of currently 18 analytical laboratories of States Parties, whose performance is regularly ascertained in proficiency tests. Samples are screened using such techniques as GC with element-specific detectors, GC/EI/MS,  $^{19}\text{F}$  and/or  $^{31}\text{P}\{^1\text{H}\}$  NMR spectroscopy, and subsequently analyzed for the identification of CWC-relevant compounds using a variety of instruments and techniques, depending on matrix and target compounds. Structural elucidation techniques are carried out. The workhorse is GC/MS, although a range of other analytical instruments and techniques are also being used. Positive identification requires the use of at least two independent techniques, one of which must be spectroscopic. A consistent result from all used techniques is required for unambiguous identification. Final confirmation is obtained when the suspected chemical is synthesized as a reference chemical, and the data recorded from the suspected and the synthesized chemical are shown to match.
44. Technical challenges for this system of Designated Laboratories relate in particular to samples with very low concentrations of the target chemical(s), or very dirty sample backgrounds. Another challenge is the analysis of samples that also contain biological or radiological agents. Advances in science and technology are likely to have an incremental effect on the capability of these

laboratories. The continuation of proficiency testing is essential, and the differences between the laboratories should be taken into account when they are tasked to perform analysis of authentic samples collected in actual CWC inspections.

45. However, there are also gaps in the analytical capabilities of the OPCW. With regard to on-site analysis, the main gap is the absence of nonscheduled chemicals from the OCAD database. With regard to off-site analysis, the main gaps relate to toxin analysis and the analysis of biomedical samples. In both cases, some of the Designated Laboratories have demonstrated capabilities to perform such analysis, but that capability has yet to be evaluated in OPCW Proficiency Testing and the OPCW has no formal basis for designating laboratories for such types of analysis. This affects, in particular, the OPCW's capability to conduct investigations of alleged use of CW as well as challenge inspections involving compliance concerns related to such chemicals. This carries serious consequences and should be addressed by the OPCW.
46. The capability to analyze biomedical samples to confirm previous exposure to CW agents is today only available in a small number of laboratories world-wide. Biomarkers of previous poisoning for most nerve and blister agents have been identified. Sensitive GC/MS/MS) and LC/MS/MS methods are applied to identify them. The analysis requires usually the capability to measure at trace concentration levels (sub-ppb) and involves the processing of complex biological matrices. It is target-compound-driven rather than a screening for a wide range of chemicals. While, at an early stage after poisoning, the free agent may still be detectable, after days or weeks the target compounds are urinary metabolites, DNA adducts in tissue, and protein adducts in blood. Challenges that need to be overcome include the low detection levels required (which call for research-grade instrumentation), the need to acquire or synthesize analytical standards (which often are not commercially available, or very expensive), and the variability of biological matrices. Evaluation criteria for the acceptance of the analytical results (e.g., on the basis of identification points) also need to be further developed because it is usually not possible to obtain full-scan spectra given the low concentration levels of the analytes.
47. The OPCW has addressed these issues, and through its SAB developed a strategy for how it will establish a capability in the field of analysis of biomedical samples. This will involve the sharing of expertise, methods, standards, and protocols between laboratories and a period of confidence building before issues related to proficiency testing and designation can be taken up. On the other hand, the issue of toxin analysis still needs to be addressed by the OPCW.

### III. Protection against the effects of chemical weapons

48. Effective protection against CW is one of the safeguards that States Parties have against regime breakout as well as against any CW threats by non-parties and non-State actors. Protection against CW is among the purposes not prohibited by the CWC, and under Article X States Parties maintain the right to apply protective measures, undertake to facilitate international cooperation between States Parties in the area of protection, and pledge to provide assistance should a State Party be threatened or attacked with CW.
49. With an increased threat of terrorist use of toxic chemicals, the requirements for chemical protection increasingly have to take account of situations where toxic and dangerous chemicals may be used against civilians in urban areas. Advances in science and technology will help improve these means of protection. Protective measures, in these evolving circumstances, have to address both the threat posed by traditional CW agents and the possibility that novel agents or "nontraditional" toxic chemicals, including toxic industrial chemicals or toxins, may be used.
50. With regard to medical response systems, many of the problems are procedural and managerial. Given the nature of chemical incidents, and in situations when considerable numbers of people may be concerned that they have been exposed, ways must be found to shorten the time it takes before victims actually receive medical treatment. This treatment is often considerably delayed,

it may only start after the victims have been moved out of the hot zone (scoop and run), initially medically assessed (triaged), and decontaminated. Early forward treatment/triage of victims prior to hospital decontamination is very important. Another difficult issue is the initial medical assessment (triage) in the hot zone, when medical personnel have donned protective equipment which impairs vision, hearing, and tactile sensing.

51. Planning and preparedness are essential for an effective medical response to chemical incidents, whether they are deliberate releases or accidents. Therefore, there is a need for regular exercises. As for deliberate releases, intelligence is another important factor. So are the speed of the initial diagnosis and the identification of the agent(s) involved. Toxicity data are often scarce, and acquiring the right expert advice in a timely manner is critical. Decontamination is slow, and the medical systems can easily be overwhelmed by self-referral of walking victims (or even the “walking well”).
52. Best practices in an emergency medical response for casualties in the hot zone of a suspected CBR incident have yet to be determined. There is a need to develop workable, pragmatic approaches to the rapid identification of responsible agents, the assessment of treatment needs, and the delivery of emergency medical care to casualties in the hot and warm zones that is appropriate for their resuscitation and stabilization prior to evacuation, while maintaining adequate protection of the responders. Furthermore, there is a need to define the training and equipment needs of medical first responders to ensure the effective delivery of these protocols.
53. With regard to medical treatments for poisoning, both supportive treatment strategies (for vesicants) and specific treatments {for nerve agents: pyridostigmine [systematic name (1-methylpyridin-1-ium-3-yl) dimethylcarbamate] pretreatment, anticholinergics (atropine [systematic name (1H,5H-tropan-3-yl) 3-hydroxy-2-phenylpropanoate]), enzyme reactivators (a variety of oximes) as well as anticonvulsants (diazepam [systematic name 7-chloro-1-methyl-5-phenyl-1,3-dihydro-2H-1,4-benzodiazepin-2-one])} are available. A variety of pyridinium, imidazolium, and quinuclidinium derivatives have been developed that show a broader spectrum than the traditional oxime reactivators. However, further funding is needed if that research were to be transformed into available treatments. In the event of terrorist use of toxic chemicals, the possible spectrum of toxic chemicals that might be used is likely to be broader than, and different from, the traditional range of CW agents. This also needs to be considered in the planning for the treatment of victims in such circumstances.
54. As for the detection of CW agents under field conditions, techniques that are currently in use or development include gas chromatography using a flame photometric detector (GC/FPD) or coupled to a mass spectrometer (GC/MS), multicapillary chromatography with ion-coupled plasma detection, portable isotope neutron spectrometry (PINS), polymer-based lanthanoid fluorescence spectroscopy, surface acoustic wave (SAW) spectroscopy, ion-mobility spectrometry (IMS and IMS/IMS), nuclear magnetic spectrometry, and lab-on-a-chip devices. A range of new detectors, ranging from flame photometric detectors to miniaturized mass spectrometers, ion traps, and hand-portable GC/MS systems, have been developed in recent years. Miniaturization has led to the development of devices such as a micro-machined field-asymmetric ion mobility spectrometer (FAIMS).
55. These developments are driven by the needs to improve protection against CW, and at the same time by the specific requirements of CW destruction programs which need detectors that can respond to low agent exposure levels [at the nationally established eight-hour time-weighted average (TWA) concentrations or equivalents]. For the latter application, fully automated continuous air monitoring systems are being used.
56. The conclusion from the 2002 Bergen workshop still stands that “many new chromatographic and spectroscopic methods show promise for detection of chemical weapon agents at low levels or in difficult sample matrices, [but] the transition of such developments from the laboratory to rugged, field portable instruments...is a slow, expensive process”. There are technical and engineering

reasons for that, such as software design, testing and debugging, preparation and testing of documentation for manufacturing (production) and for routine instrument operations as well as for use in training operators and other personnel, laboratory validation and field testing in comparison to already-existing instruments. There are also economic/market reasons: companies are not prepared to invest very large sums in developing a new item of equipment if there is only a limited market for such equipment.

57. In conclusion, current mature technologies are expected to continue to play a key role in the detection of CW agents during the next five years (in particular: GC/FPD, GC/MS, IMS). Miniaturized versions of mature technologies capable of CW detection are now becoming commercially available (GC/FPD, GC/FAIMS, MS). New ionization methods that enhance the ability of mass spectrometers to interrogate surfaces (liquids and solids) may greatly expand the effectiveness of inspections in the future—if these methods can be miniaturized and reduced in cost. Biosensors should be considered for their utility as detection devices given their specificity and sensitivity.
58. With regard to decontamination, improvements in cost, portability, and environmental friendliness are needed. Requirements are taking account of the changing nature of military operations, which are more likely to take place in urban areas with civilians present. Experience has shown that standard (military) decontamination methods do not work effectively in urban areas. There is a need for smaller and easier-to-transport decontamination equipment that requires fewer personnel to operate. Decontamination chemicals should be environmentally friendly and less corrosive/aggressive so they can be used in urban areas as well as on sensitive military equipment (e.g., microemulsions, enzymatic systems or reactive nanoparticles). Progress has also been made with regard to new materials for skin decontamination.
59. Systematic research and development over recent decades has led to the introduction of new decontamination solutions, emulsions, ointments, gels, pastes, foams, and adsorption (chemisorption) powders. New directions for personnel decontamination include, for example, the use of sodium peroxide-surfactant mixtures, alcoholates in aprotic solvents, or chemisorptive powders based on bentonite. For the decontamination of personnel as well as equipment, vehicles, and the like, universal decontamination solutions have been introduced, and equipment for the decontamination can deal with anything from an individual to the mass decontamination of troops and their equipment and vehicles (in drive-through mode).
60. In sum, the advances in the life sciences, medicine, chemistry, and enabling technologies (including nanotechnology, engineering, and information technology) are all expected to improve chemical protection systems and methods. The current investment in research and development for protective purposes is significant, partly driven by terrorism concerns—which need to recognize that toxic chemicals different from the traditional CW agents may be used in such cases. Expectations should, however, remain realistic: As with other developments, there is a long way from demonstrating the suitability of a new method or material for protective purposes (which may work well under idealized laboratory conditions) to actually fielding a new instrument, protective material/device, or medical treatment for practical use.

#### IV. Opportunities in the field of international cooperation

61. The promotion of the economic and technological development of the States Parties through enhanced international cooperation and exchanges in the field of peaceful uses of chemistry is one of the core objectives of the CWC. In 2006, the OPCW adopted a decision on how this aspect of the CWC is to be implemented [4]. Of particular relevance for this report is paragraph 3 of that decision, which stated that the OPCW Secretariat shall develop international cooperation programs:

- that meet the needs of the States Parties for capacity-building and economic and technological development through international cooperation in the field of chemical activities for purposes not prohibited under the CWC, within the budgetary resources of the OPCW;
  - that contribute to the effective and nondiscriminatory implementation of the CWC;
  - that focus on the specific competencies of the OPCW;
  - that avoid duplicating the efforts of other international organizations; and
  - whose high quality and cost-effectiveness are ensured through continuous evaluation by the Secretariat, in consultation with the States Parties.
62. One area of international cooperation that the CWC explicitly mentions, in Article X, is the protection against CW. Scientific and technological developments that are relevant in this respect have been discussed above. A call for enhanced international cooperation among States Parties in these areas of science and technology would be consistent with the objectives of the CWC, and meet the criteria adopted in 2006 for the development of OPCW international cooperation programs.
63. Another area where the OPCW has over the years acquired competence in facilitating international cooperation is the destruction of CW. Relevant scientific and technical advances have already been discussed in a previous section of this report. The OPCW is accumulating data about protective measures and technologies to manage old and abandoned munitions locations. Such a “data bank” would be useful for States Parties in case they discover such sites and need to take remedial action.
64. The workshop in Zagreb reaffirmed the conclusion of many recent reviews of advances in science and technology, namely, that the advances in the life sciences and related technological fields are likely to make significant contributions to the benefit of humankind. International cooperation and exchanges in these fields of science and technology have great potential for improving public health and for environmentally and economically sustainable development. Therefore, the OPCW would be well advised to focus its international cooperation efforts on the kinds of scientific and technological research reviewed in this report, consistent with its own decision on the implementation of CWC Article XI. International cooperation and exchanges in these areas should be pursued in recognition of the fact that they must be fully consistent with the disarmament and nonproliferation obligations of the CWC.
65. The OPCW should, in the further development of its international cooperation program, create partnerships with other international organizations that work in the field of national capacity-building for chemicals management. In particular, the OPCW should consider more fully cooperating with such mechanisms as the SAICM, UNEP’s action to prevent international trade in toxic chemicals, and the Green Customs Initiative as well as the European REACH initiative.

## V. Awareness-raising, education, and outreach

66. The First CWC Review Conference observed that “a valuable aspect of national implementation measures involves ensuring that the chemical industry, the scientific and technological communities, the armed forces of the States Parties, and the public at large are aware of and knowledgeable about the prohibitions and requirements of the Convention”. After the First CWC Review Conference, a proposal for a joint project on chemistry education, outreach, and the professional conduct of chemists was agreed in early 2004 between the OPCW and IUPAC. The SAB considered and encouraged the project at its meeting in March 2005, and the Director-General of the OPCW issued a note to the Executive Council in May 2005 stating that “[as] regards education and outreach, the Director-General notes the state of preparations for an international workshop being organized jointly by the OPCW and the International Union of Pure and Applied Chemistry, which will focus on how the requirements of the Convention can be better reflected in codes of professional conduct and ethics as well as in chemistry education.” Following the international

workshop in Oxford, UK, in July 2005, an international project was launched by IUPAC to develop educational material on the multiple uses of chemicals and related ethical matters. The results of this project so far were presented in Zagreb in a poster. The project has resulted in the preparation of a series of materials and case studies—now available in all six CWC languages—that will enable chemistry teachers at university level (and also high school level) to provide lectures on the issue as well as run interactive workshops. The material will be distributed through various IUPAC channels as well as posted on the Web.

67. These developments are evolving in parallel with efforts in the life sciences community under the BWC to provide for effective governance of the life sciences to prevent abuse as well as unintentional adverse consequences of new discoveries or scientific work. It is worth noting the conclusion drawn by a representative scientific group that assessed similar issues in the field of biological risks: It concluded that “[n]ational and international scientific organizations and industry should encourage and engage those involved with scientific endeavours to increase awareness of the Convention and dual use issues, thereby both promoting in depth implementation of the Convention and ensuring vigilance when work with dual use potential is undertaken.” [5]
68. The Zagreb workshop concluded that further efforts should be made in reaching out to the scientific community and to all those engaged in chemicals, and in promoting the adoption of codes of conduct to ensure full CWC compliance as well as the incorporation of the norms and requirements of the CWC into chemistry education.

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## APPENDIX 1: THE CHEMICAL WEAPONS CONVENTION: AN OVERVIEW

### Introduction

The CWC [6] totally prohibits the development, production, acquisition, stockpiling, or retention of CW. It defines chemical weapons as meaning the following, together or separately:

- (a) *Toxic chemicals and their precursors, except where intended for purposes not prohibited under this Convention, as long as the types and quantities are consistent with such purposes; [Emphasis added]*
- (b) *Munitions and devices, specifically designed to cause death or other harm through the toxic properties of those toxic chemicals specified in subparagraph (a), which would be released as a result of the employment of such munitions and devices;*

- (c) *Any equipment specifically designed for use directly in connection with the employment of munitions and devices specified in subparagraph (b).*

The text in bold is referred to as the **general purpose criterion**, which ensures that all toxic chemicals and their precursors are embraced by the Convention *except where intended for purposes not prohibited under the Convention*. Toxic chemicals are defined in the Convention as meaning:

*Any chemical which through its chemical action on life processes can cause death, temporary incapacitation or permanent harm to humans or animals. This includes all such chemicals, regardless of their origin or of their method of production, and regardless of whether they are produced in facilities, in munitions or elsewhere.*

All chemicals that can cause death, temporary incapacitation, or permanent harm to humans or animals are thus prohibited unless they are in types and quantities consistent with their intended uses for purposes not prohibited under the Convention which are defined in the Convention as:

- (a) *Industrial, agricultural, research, medical, pharmaceutical or other peaceful purposes;*  
(b) *Protective purposes, namely those purposes directly related to protection against toxic chemicals and to protection against chemical weapons;*  
(c) *Military purposes not connected with the use of chemical weapons and not dependent on the use of the toxic properties of chemicals as a method of warfare;*  
(d) *Law enforcement including domestic riot control purposes.*

The CWC was opened for signature in January 1993 and entered into force on 29 April 1997, which was 180 days after the 65<sup>th</sup> State Party had deposited its instrument of ratification. In July 2007, the Convention has 182 States Parties [7].

Article VIII of the Convention, which establishes the Organization to achieve the object and purpose of the Convention, includes the requirement to undertake periodic reviews of the operation of the Convention:

22. *The Conference shall not later than one year after the expiry of the fifth and the tenth year after the entry into force of this Convention, and at such other times within that time period 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.*

It will be noted that such reviews are required to take into account “any relevant scientific and technological developments.”

In addition, Part IX of the Verification Annex to the Convention which addresses the regime for OCPFs includes a requirement that:

26. *At the first special session of the Conference convened pursuant to Article VIII, paragraph 22, the provisions of this Part of the Verification Annex shall be re-examined in the light of a comprehensive review of the overall verification regime for the chemical industry (Article VI, Parts VII to IX of this Annex) on the basis of the experience gained. The Conference shall then make recommendations so as to improve the effectiveness of the verification regime.*

The First CWC Review Conference initiated this comprehensive review of the overall verification regime for the chemical industry in order to re-examine the provisions for OCPFs, and made initial recommendations so as to improve the effectiveness of the verification regime. The issue remains on the

agenda of the OPCW's Executive Council, however, and the Second CWC Review Conference may be expected to address it again.

The regime for the chemical industry is specified in Article VI of the Convention which addresses "Activities Not Prohibited under this Convention". The key requirement is stated in paragraph 2 that:

2. *Each State Party shall adopt the necessary measures to ensure that toxic chemicals and their precursors are only developed, produced, otherwise acquired, retained, transferred, or used within its territory or in any other place under its jurisdiction or control for purposes not prohibited under this Convention. To this end, and in order to verify that activities are in accordance with obligations under this Convention, each State Party shall subject toxic chemicals and their precursors listed in Schedules 1, 2 and 3 of the Annex on Chemicals, facilities related to such chemicals, and other facilities as specified in the Verification Annex, that are located on its territory or in any other place under its jurisdiction or control, to verification measures as provided in the Verification Annex.*

The Convention in its Annex on Chemicals assigns chemicals judged to present a risk to the Convention into three Schedules according to the following criteria:

#### **Guidelines for Schedule 1**

1. *The following criteria shall be taken into account in considering whether a toxic chemical or precursor should be included in Schedule 1:*
  - (a) *It has been developed, produced, stockpiled or used as a chemical weapon as defined in Article II;*
  - (b) *It poses otherwise a high risk to the object and purpose of this Convention by virtue of its high potential for use in activities prohibited under this Convention because one or more of the following conditions are met:*
    - (i) *It possesses a chemical structure closely related to that of other toxic chemicals listed in Schedule 1, and has, or can be expected to have, comparable properties;*
    - (ii) *It possesses such lethal or incapacitating toxicity as well as other properties that would enable it to be used as a chemical weapon;*
    - (iii) *It may be used as a precursor in the final single technological stage of production of a toxic chemical listed in Schedule 1, regardless of whether this stage takes place in facilities, in munitions or elsewhere;*
  - (c) *It has little or no use for purposes not prohibited under this Convention.*

#### **Guidelines for Schedule 2**

2. *The following criteria shall be taken into account in considering whether a toxic chemical not listed in Schedule 1 or a precursor to a Schedule 1 chemical or to a chemical listed in Schedule 2, part A, should be included in Schedule 2:*
  - (a) *It poses a significant risk to the object and purpose of this Convention because it possesses such lethal or incapacitating toxicity as well as other properties that could enable it to be used as a chemical weapon;*
  - (b) *It may be used as a precursor in one of the chemical reactions at the final stage of formation of a chemical listed in Schedule 1 or Schedule 2, part A;*

- (c) *It poses a significant risk to the object and purpose of this Convention by virtue of its importance in the production of a chemical listed in Schedule 1 or Schedule 2, part A;*
- (d) *It is not produced in large commercial quantities for purposes not prohibited under this Convention.*

### **Guidelines for Schedule 3**

- 3. *The following criteria shall be taken into account in considering whether a toxic chemical or precursor, not listed in other Schedules, should be included in Schedule 3:*
  - (a) *It has been produced, stockpiled or used as a chemical weapon;*
  - (b) *It poses otherwise a risk to the object and purpose of this Convention because it possesses such lethal or incapacitating toxicity as well as other properties that might enable it to be used as a chemical weapon;*
  - (c) *It poses a risk to the object and purpose of this Convention by virtue of its importance in the production of one or more chemicals listed in Schedule 1 or Schedule 2, part B;*

*It may be produced in large commercial quantities for purposes not prohibited under this Convention.*

## **APPENDIX 2: ACRONYMS AND INITIALISMS**

BTWC	Biological and Toxin Weapons Convention or Biological Weapons Convention (BWC)
CBR	chemical, biological, radiological
CW	chemical weapons
CWC	Chemical Weapons Convention
FAIMS	field-asymmetric ion-mobility spectrometry
GC	gas chromatography
GC/FPD	gas chromatography/flame photometric detector
GC/EI/MS	gas chromatography/element isotope/mass spectrometry
GC/MS	gas chromatography/mass spectrometry
ICCA	International Council of Chemical Associations
IMS	ion-mobility spectrometry
IR	infrared
ISO	International Organization for Standardization
IT	information technology
IUPAC	International Union of Pure and Applied Chemistry
LC/MS	liquid chromatography/mass spectrometry
NAFTA	North American Free Trade Agreement
NMR	nuclear magnetic resonance
OCAD	OPCW Central Analytical Database
OCPF	other chemical production facilities
ODMS	OPCW Dual Mode Software
OPCW	Organisation for the Prohibition of Chemical Weapons
PINS	portable isotope neutron spectrometer
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals (European Union Chemicals Agency)

SAB	Scientific Advisory Board
SAICM	Strategic Approach to International Chemicals Management
SAW	surface acoustic wave
TWA	time-weighted average
UNEP	United Nations Environmental Program