

THE SCIENCE OF  
DESTRUCTION AND  
VERIFICATION

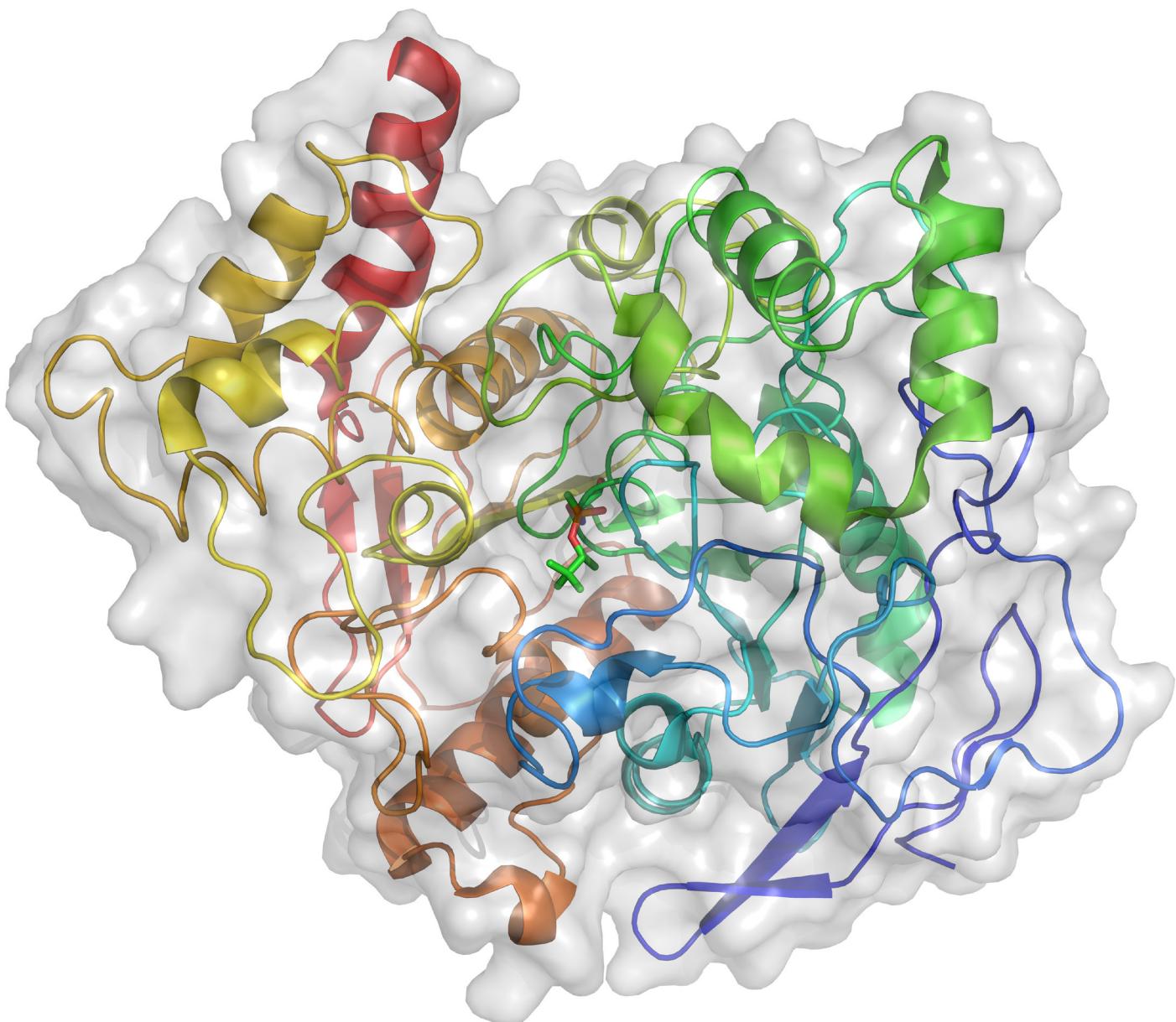
THE CONVERGENCE OF  
CHEMISTRY AND BIOLOGY

Feature Article:  
Plants as Nerve Agent Detectors

SCIENCE AND  
INTERNATIONAL  
COLLABORATION

# OPCW Today

Volume 3 No. 1 ♦ Aug 2014  
[www.opcw.org](http://www.opcw.org)



## SCIENCE AND TECHNOLOGY



ORGANISATION FOR THE PROHIBITION OF CHEMICAL WEAPONS

# **OPCW Today Impressum**

*OPCW Today* is published twice a year and distributed without charge to readers interested in the OPCW and the peaceful uses of chemistry.

Articles and extracts from articles appearing in *OPCW Today* may be freely used elsewhere provided that the material is reproduced verbatim and acknowledgement of its source is made. However, if the attribution indicates that the author is not an OPCW staff member, permission to republish other than for the use of review must be sought from the author or originating organisation. Views expressed in any signed article appearing in *OPCW Today* do not necessarily represent those of the OPCW and the OPCW accepts no responsibility for them.

***OPCW Today* is produced by:**

**Organisation for the Prohibition of Chemical Weapons**

Johan de Wittlaan 32  
2517 JR The Hague  
The Netherlands

**Tel:** +31 (0) 70 416 3000  
**Fax:** +31 (0) 70 416 3044

**E-mail:** journal@opcw.org  
**Website:** www.opcw.org

**Contributors:** Roberto Martínez Álvarez, Matthew J. Baker, Marc-Michael Blum, Matthew R. Gravett, Hugh Gregg, Murat Gulay, Michelle Holmes, Farrha B. Hopkins, William Kane, Martin Kalinowski, Murty Mamidanna, D. G. Cerys Rees, James R. Riches, Adam J. Self, Alejandra Graciela Suárez, Christopher M. Timperley, Andrew J. Webb, Sergey Zinoviev

**Editors:** Jonathan Forman (Science Policy Adviser), Amirhossein Imani, Stian Holen (Secretary to the Science Advisory Board)

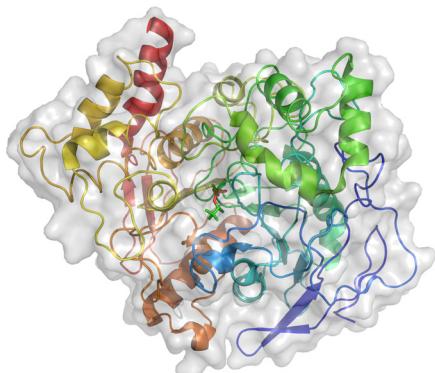
**Photography:** Eric Vander Borght, Oluwasesan Falayi, Daniel Feakes

**Production:** Zixi Li and Thomas Cummings

**Printing:** OPCW Reprographic Centre

## Table of Contents

• Foreword by the Director-General.....	4
• The OPCW Scientific Advisory Board.....	6
• Scientific Contributions of the Technical Secretariat.....	8
• Science and Technology in the Destruction of Chemical Weapons	
The Chemistry of Destruction.....	10
High Temperature Incineration.....	14
• Science and Technology Dimensions of Verification	
The Temporary Working Group on Verification.....	17
Conducting Analysis of Biomedical Samples to Assess Exposure to Organophosphorus Nerve Agents.....	18
The Secure Information Exchange (SIX) Project.....	22
• The Convergence of Chemistry and Biology	
The Temporary Working Group on the Convergence of Chemistry and Biology.....	25
 Peer-Reviewed Feature Article: Plants as Nerve Agent Detectors.....	27
• The Role of Science and Technology in International Collaboration	
Science for the Comprehensive Nuclear-Test-Ban Treaty.....	37
Scientific Research – At the Core of the OPCW International Cooperation Programme.....	41



**Cover:** Non-aged soman (GD) conjugate of *Torpedo Californica* acetylcholinesterase (Protein Data Bank Structure 2WFZ). The enzyme is depicted with a transparent solvent accessible surface and secondary structure elements; the GD moiety is in stick representation. See the contribution from the OPCW Laboratory “Conducting Analysis of Biomedical Samples to Assess Exposure to Organophosphorus Nerve Agents” on page 18 for further details on acetylcholinesterase, its nerve agent conjugates, and the ageing process.

# Foreword by the Director-General

We are fortunate to be living in an era of unprecedented scientific advancement and technological innovation. Technologies once confined to the realm of science fiction are today a reality, with breakthroughs and new discoveries continuing to capture our imagination and find their way into our daily lives.

Science and technology directly inform several key articles of the Chemical Weapons Convention, ranging from those that define what constitutes a chemical weapon, through to those ensuring completeness of declarations, the application of sampling and analysis and other verification methodologies, the processes for inspections and investigations, and destruction methodologies, to those governing assistance and protection and outreach to scientific communities. We need to remain alert to the fact that the dynamism of science can both improve and potentially undermine our ability to maintain an effective disarmament regime.

For this reason, we must look at science and technology as a priority in our work, actively engage with scientific experts and ensure that policymakers use scientific insights in their decision making.

This issue of OPCW Today is devoted to science and technology relevant to the effective implementation of the Convention. There are descriptive contributions about why science and science advice are important, complemented by more detailed technical contributions on what scientists do and how they communicate their work. The technical reports have been peer-reviewed and are certain to stimulate lively discussion among our experts on the science and technology dimensions of our work.

I am pleased to see so many contributions and information stemming from the work of the OPCW Scientific Advisory Board (SAB) and its temporary working groups (TWGs).

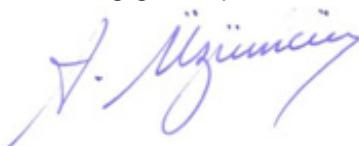
The identification of chemical agents from environmental and biomedical samples in last year's investigation of alleged use of chemical weapons,

and the methods employed by inspectors working in the OPCW-UN Joint Mission in the Syrian Arab Republic, draw upon knowledge coming directly out of the work of our Scientific Advisory Board, past and present. With these sorts of challenges, alongside new and emerging ones, the work of the SAB is ever more crucial to maintaining credible and effective verification, including a well-trained and well-equipped inspectorate and laboratory, as we look toward the future.

The Chemical Weapons Convention has stood the test of time in prohibiting the development, production, stockpiling and use of chemical weapons. For it to continue to do so, it is imperative that we

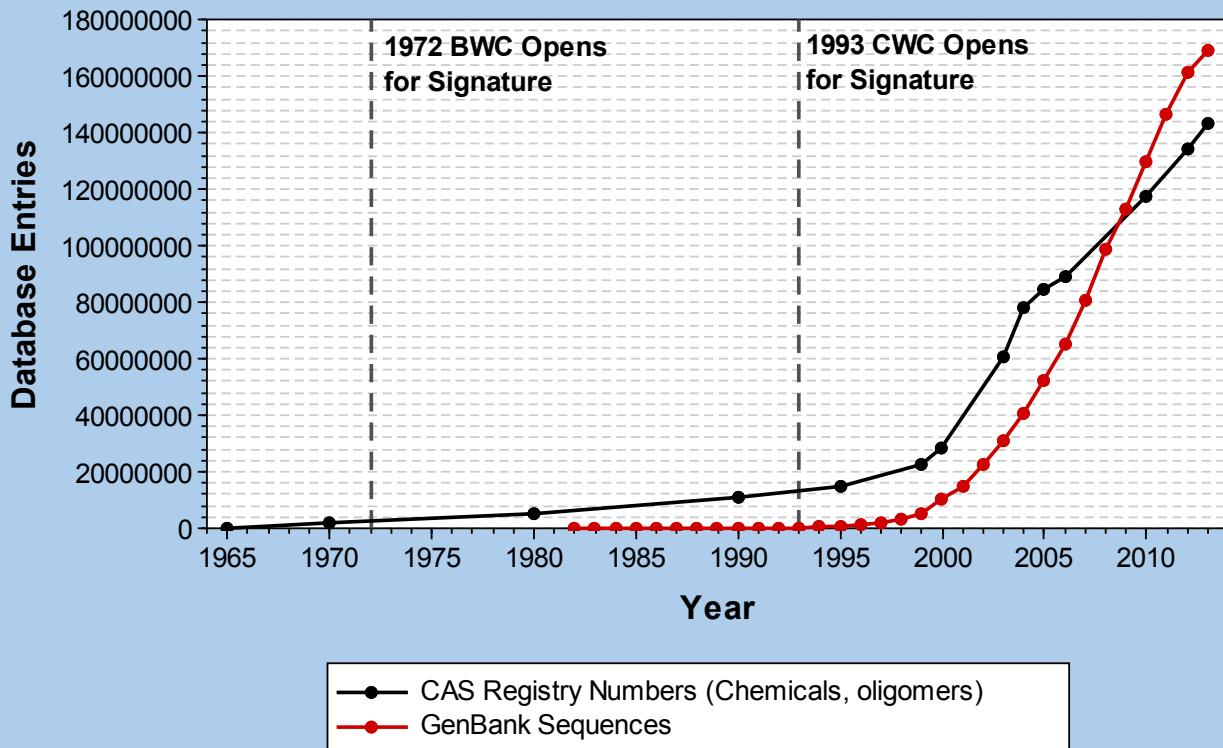
use our partnerships with science to ensure the Convention's ongoing relevance as advances in science and technology reshape our future.

These partnerships will remain a vital investment in the contribution made by the Convention towards enhancing global peace and security.



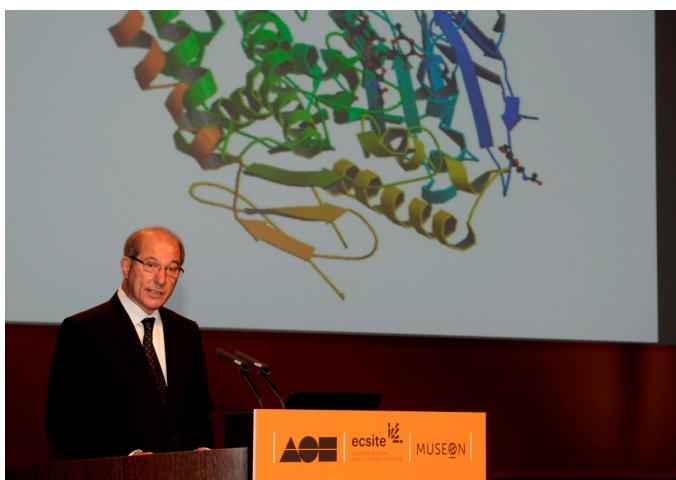
Ahmet Üzümcü  
OPCW Director-General

### The Pace of Scientific Discovery from 1965-2013



The chart illustrates the increasing pace of scientific discovery with the number of Chemical Abstract Services (CAS) entries and GenBank database genetic sequence entries by year from 1965 to 2013. CAS numbers represent all chemical substances in their various forms (elements, compounds, alloys, and oligomers in their various isomeric forms and chemical phases); in 2013 more than 87 million of the total CAS entries represented unique organic and inorganic chemical compounds. In 2013, approximately 15,000 CAS numbers were added to the database every day. Over 110 million CAS numbers have been added to the database since 1993 when the Chemical Weapons Convention (CWC) opened for signature. The GenBank database is one of a number of databases that store genetic information; the volume of sequences in this database at the end of 2013 represented an average of more than 2 million entries added per day since the end of 2012. In 1972 when the Biological Weapons Convention (BWC) opened for signature, the technologies used to generate the sequence data being recorded did not exist.

The Director-General presenting a keynote address at the 2014 European Network of Science Centres and Museums (ecsite) Annual Conference in The Hague



# The OPCW Scientific Advisory Board

By Professor Alejandra Graciela Suárez



**Members of the Scientific Advisory Board at its Twenty-First Session (The Hague, 23 June 2014).** From left to right: (Back Row) Dr Muhammad Zafar-Uz-Zaman (Pakistan), Dr Augustin Baulig (France), Dr Carlos David Gonzalez Berruti (Uruguay), Mr Francois Mauritz van Straten (South Africa), Mr Valentin Rubaylo (Russian Federation), Dr Michael Geist (Germany); (Middle Row) Dr Koji Takeuchi (Japan), Professor Djafer Benachour (Algeria), Professor Roberto Martinez Álvarez (Spain), Professor Ferruccio Trifirò (Italy), Mr Cheng Tang (China), Mr William Kane (United States of America), Professor Veronica Borrett (Australia), Dr Syed Raza (India), Jonathan Forman (Technical Secretariat, Science Policy Adviser), Stian Holen (Technical Secretariat, Secretary to the SAB); (Front Row) Professor Slawomir Neffe (Poland), Professor Mohammad Abdollahi (Islamic Republic of Iran), Dr Chris Timperley (United Kingdom, SAB Vice-Chair), Professor Alejandra Graciela Suárez (Argentina, Chair of SAB), John Sequeira (Technical Secretariat, Director of Administration and Acting Director-General on 23 June), Professor Mongia Said Zina (Tunisia), Dr Nicia Maria Fusaro Mourão (Brazil), Professor Slavica Vučinić; (Serbia), Professor Flerida Cariño (Philippines), Professor Paula Vanninen (Finland), Professor Volodymyr Zaitsev (Ukraine).

The OPCW Scientific Advisory Board (SAB) was established in 1998, in accordance with Article VIII of the Chemical Weapons Convention, to enable the Director-General to render specialised advice in the areas of science and technology to the OPCW policy-making organs and to the States Parties to the Chemical Weapons Convention (CWC).

The SAB consists of 25 members<sup>1</sup> appointed by the Director-General. The members of the Board collectively cover a broad range of technical dimensions. They serve in their individual capacity as independent experts, for a maximum of two consecutive three-year terms of office. The Scientific Advisory Board appoints by consensus a Chair and a Vice-Chair by annual election from among its members.

Since its first meeting in 1998, the SAB has met once or twice per year and will meet for the 22nd time in June 2015. The report of each meeting includes conclusions

and recommendations of the SAB, which are developed through a consensus process and reported to the Director-General,<sup>1</sup> who then makes available their reports, together with his own response, to CWC States Parties and the public.<sup>2</sup>

Every five years, the SAB prepares a comprehensive report on scientific and technological developments for the purpose of assisting the Conference of the States Parties in its special sessions to review the operation of the Convention.

The most recent such report was prepared for the Third Review Conference (RC-3) of April 2013. In preparing these reports, the SAB reviews developments in science and technology in the two years prior to the review conference. The SAB's report for RC-3 (RC-3/DG.1) was issued on 29 October 2012.<sup>3</sup> For the first time in a review conference, the Chair of the SAB presented the Board's key findings during a plenary session.

As reflected in the RC-3 outcome document,<sup>4</sup> the States Parties expressed strong appreciation for the work of the SAB and recommended continued emphasis on science and technology.

### Temporary working groups

In consultation with the Scientific Advisory Board, the Director-General establishes temporary working groups (TWGs) of scientific experts to provide recommendations on specific issues. TWGs are chaired by a member of the SAB and may also include experts who are not members of the SAB. The report of each temporary working group is reviewed by the Scientific Advisory Board and is attached unchanged to its annual report. There are currently two TWGs that are active: one on verification, whose work is described on page 17 of this issue, and one on education and outreach in science and technology, whose work was described in the previous edition of *OPCW Today* (Volume 2, Number 5, December 2013).<sup>5</sup>

Previous TWGs have included: sampling and analysis, scientific and technical aspects of reporting ricin production, OPCW's analytical procedures and capabilities for verification, requirements and specifications for on-site monitoring equipment, technologies for the destruction of chemical weapons, adamsite, low-concentration limits for Schedule 2A and 2A\* chemicals, biomedical samples, and the convergence of chemistry and biology.

The TWG on Convergence of Chemistry and Biology completed its two-year term recently and produced a report of its findings with recommendations for the Director-General and States Parties. This work covered a broad range of developments across scientific disciplines and is described on page 25 of this issue.

SAB and TWG members also participate in a range of events where they present the activities carried out by the SAB and its findings; these events have included scientific meetings as well as conferences on other international disarmament conventions such as the Biological Weapons Convention.

The Chair and Vice-Chair of the SAB periodically make presentations to the States Parties, and the SAB and TWG members have actively participated in the most recent Annual Meetings of National Authorities.

All of these actions further increased visibility of the work of the SAB and give SAB members the opportunity to interact and strengthen relationships with other scientific professionals interested in contributing to disarming our world of weapons of mass destruction.

The members of the SAB and the TWGs work on a voluntary basis. The time and effort the members contribute to the work of the SAB and the TWGs has a strong impact on the overall output of the Board. This means hard work during the meetings as well as intensive intersessional work.

The commitment from all the SAB and TWG members, past and present, demonstrates the strong support to the work of the OPCW to create a world free of chemical weapons, as was recognised by the award of the Nobel Peace Prize in 2013.



**Professor Alejandra Graciela Suárez** (of Argentina) became SAB chair in June 2013. She is a professor at the Facultad de Ciencias Bioquímicas y Farmacéuticas, Universidad Nacional de Rosario and a member of the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET). Her areas of expertise are organic and organo-metallic chemistry and green chemistry.

### References

1. [www.opcw.org/about-opcw/subsidiary-bodies/scientific-advisory-board/](http://www.opcw.org/about-opcw/subsidiary-bodies/scientific-advisory-board/)  
Reports and other documents from the SAB can be found at
2. [www.opcw.org/about-opcw/subsidiary-bodies/scientific-advisory-board/documents/](http://www.opcw.org/about-opcw/subsidiary-bodies/scientific-advisory-board/documents/)
3. [www.opcw.org/index.php?eID=dam\\_frontend\\_push&docID=15865](http://www.opcw.org/index.php?eID=dam_frontend_push&docID=15865)
4. [www.opcw.org/fileadmin/OPCW/CSP/RC-3/en/rc303\\_\\_e\\_.pdf](http://www.opcw.org/fileadmin/OPCW/CSP/RC-3/en/rc303__e_.pdf)
5. [www.opcw.org/fileadmin/OPCW/OPCW\\_Today/OPCW\\_Today\\_-\\_Vol\\_2\\_No\\_5.pdf](http://www.opcw.org/fileadmin/OPCW/OPCW_Today/OPCW_Today_-_Vol_2_No_5.pdf)

# Scientific Contributions of the Technical Secretariat

**A**ccess to scientific expertise through the Scientific Advisory Board has been and continues to be highly important for implementation of the Chemical Weapons Convention. Equally as important is ensuring that technical expertise is also represented within the staff of the Technical Secretariat.

This was most recently exemplified by Secretariat staff with training as chemists and chemical engineers who supported the missions in the Syrian Arab Republic from their very outset, serving as inspectors, working as analytical chemists, supporting the munitions and chemical weapons experts in destruction activities, and providing technical advice and evaluation in the selection process for the commercial facilities that have incinerated priority 1 and priority 2 chemicals removed from the Syrian Arab Republic and effluents generated on the MV Cape Ray.

These staff members represent units across the Secretariat and complement a long list of previous staff members with scientific backgrounds. The following is a list of peer-reviewed contributions to the scientific literature published by Technical Secretariat staff members during their tenure at the OPCW.

## **1997**

Manley RG. 1997 European experience with the disposal of old chemical weapons. *NATO ASI Series, Series 1: Disarmament Technologies, 13 (Analytical Chemistry Associated with the Destruction of Chemical Weapons)*, 15-26.

## **1998**

Manley RG. 1998 The problem of old chemical weapons which contain “mustard gas” or organoarsenic compounds: an overview. *NATO ASI Series, Series 1: Disarmament Technologies, 19 (Arsenic and Old Mustard: Chemical Problems in the Destruction of Old Arsenical and Mustard Munitions)*, 1-16.

## **2002**

Gee J. 2002 Advances in science and technology. Maintaining the effectiveness of the Chemical Weapons Convention. *Pure and Applied Chemistry, 74*, 2229-2234.

Manley RG. 2002 Verification under the Chemical Weapons Convention. A reflective review. *Pure and Applied Chemistry, 74*, 2235-2240.

## **2008**

Sokolowski MS, Konopski L, Froebe Z. 2008 Detection of lewisite-2 in the presence of alcohols and/or thiodiglycol in aqueous matrices. *Phosphorus, Sulfur and Silicon and the Related Elements, 183*, 1630-1640.

## **2010**

Terzic O, 2010 Screening of degradation products, impurities and precursors of chemical warfare agents in water and wet or dry organic liquid samples by in-sorbent tube silylation followed by thermal desorption-gas chromatography-mass spectrometry. *Journal of Chromatography A, 1217*, 4987-4995.

**2011**

Amphaisri K, Palit M, Mallard G. 2011 Thermally assisted methylation and subsequent silylation of scheduled acids of Chemical Weapons Convention for onsite analysis and its comparison with the other methods of methylation. *Journal of Chromatography A*, **1218**, 972-980.

Palit M, Mallard G. 2011 Dispersive derivatization liquid-liquid extraction of degradation products/precursors of mustards and V-agents from aqueous samples. *Journal of Chromatography A*, **1218**, 5393-5400.

Sanyal D, Rani A, Alam S, Gujral S, Gupta R. 2011 Development, validation, and uncertainty measurement of multi-residue analysis of organochlorine and organophosphorus pesticides using pressurized liquid extraction and dispersive-SPE techniques. *Environmental Monitoring and Assessment*, **182**(1-4), 97-113.

**2012**

Terzic O, Swahn I, Cretu G, Palit M, Mallard G. 2012 Gas chromatography-full scan mass spectrometry determination of traces of chemical warfare agents and their impurities in air samples by inlet based thermal desorption of sorbent tubes. *Journal of Chromatography A*, **1225**, 182-192.

**2013**

Terzic O, Bartenbach S, de Voogt P. 2013 Determination of lewisites and their hydrolysis products in aqueous and multiphase samples by in-sorbent tube butylthiolation followed by thermal desorption-gas chromatography-full scan mass spectrometry. *Journal of Chromatography A*, **1304**, 34-41.

**2014**

Schmidt C, Breyer F, Blum MM, Thiermann H, Worek F, John H. 2014 V-type nerve agents phosphorylate ubiquitin at biologically relevant lysine residues and induce intramolecular cyclization by an isopeptide bond. *Analytical Bioanal Chem*, **406** (21).

Üzümçü A. 2014 The Chemical Weapons Convention—disarmament, science and technology. *Analytical Bioanal Chem*, **406** (21).



OPCW staff on a laboratory visit

# The Chemistry of Destruction

By Professor Roberto Martínez Álvarez

## Abstract

The destruction of stockpiled chemical weapons is a complex process involving multiple steps and chemistries, and appropriate technical capabilities. We report herein a short overview of the different methods used for the destruction of chemical weapons.

## Introduction

As defined by the Chemical Weapons Convention (CWC) signed by 190 States Parties, any toxic chemical or precursor that can cause death, injury, temporary incapacitation or sensory irritation is a chemical weapon.<sup>1</sup> Several countries have declared chemical weapons, amounting to nearly 70,000 tonnes of toxic agents in 8.6 million munitions and containers. The Convention requires the States Parties of the Convention to destroy their chemical weapons within ten years after the CWC entered into force in 1997.

However, technical and economic problems found in this difficult process have resulted in requests from some States Parties for an extension to this deadline.<sup>2</sup> Chemical weapons can be destroyed easily or safely, but not both. Precursors which are starting materials for the synthesis of chemical weapons, munitions and any other delivery devices are also considered chemical weapons and must also be destroyed under the Convention.

Before the CWC entered into force, dumping of chemical munitions and containers at sea was the simplest solution to eliminate the chemical agents remaining after the First and Second World Wars.

Unfortunately, drums of waste are now often found by fisherman in the Baltic Sea. In the 1950s, large quantities of dangerous materials stockpiled in the United Kingdom were dumped in the North Sea and the last sea-dumping operation was carried out by the United States Army in the Atlantic Ocean in the 1970s. Burning and burying were also commonly employed historical methods.

Under the CWC, States Parties have obligations to ensure that destruction is not dangerous for humans or the environment, requiring clean and safe methods to achieve the destruction of chemical weapons. The OPCW continuously monitors the destruction of chemical weapons at the specialised facilities where these operations take place.

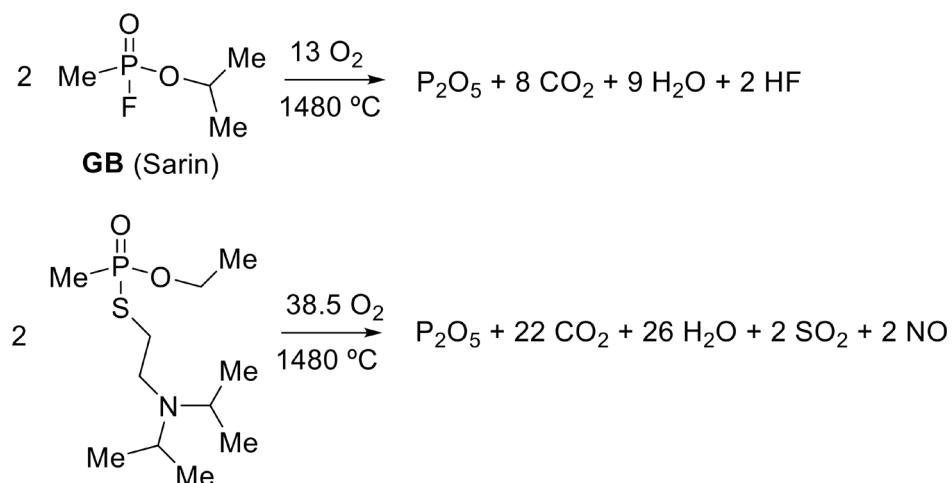
It is important to note that the OPCW also monitors the destruction of old chemical weapons (manufactured before 1925 or produced between 1925 and 1946 that have deteriorated to such extent they are no longer useable) and abandoned chemical weapons (abandoned in one State by another State without consent on or after 1 January 1946).

## Incineration

Many technologies have been considered for safe destruction of chemical weapons. Among these, two are used worldwide: incineration and neutralisation by means of hydrolysis. In 1982, the National Research Council (NRC, USA) endorsed incineration as the recommended method, known as the baseline system. The first full-scale facility using incineration was the Johnston Atoll Chemical Agent Disposal System (JACADS). This early incineration technology subjected material to a single burn but produced noxious fumes that could enter the atmosphere. Because the single burn often produced contaminated matter, the US Army improved the technology at the Tooele Chemical Agent Disposal Facility (TOCDF).

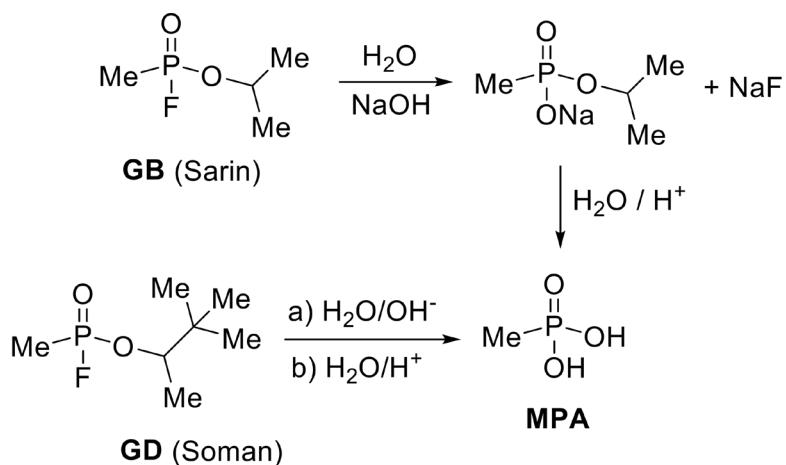
The second-generation process consists of four steps: first, the separation of chemical agents and explosives or propellants; second, the incineration of either agents, or energetic and shipping materials; third, the thermal decontamination of metal parts of storage containers; and finally the fourth step, treatment of gaseous effluents and the disposal of liquid and solid wastes.<sup>3</sup>

The total incineration process pathways for the nerve agents sarin and VX are illustrated in Figure 1.

**Figure 1. Combustion reactions of sarin (GB) and VX**

Blister agents containing arsenic can be similarly incinerated. However, one of the combustion products is arsenic oxide, a substance that can undergo sublimation; this requires its immobilisation by a secondary reaction with sodium hydroxide, leading to the formation of sodium arsenite which in turn is immobilised in cement.

can be used to perform a nucleophilic substitution at the phosphorous atom to afford non-toxic materials in the corresponding hydrolysate. For example, sarin (GB) and soman (GD) can be detoxified by alkaline hydrolysis, to yield methylphosphonic acid (MPA) as the main product (Figure 2).

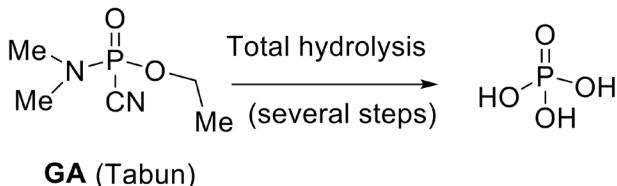
**Figure 2. Alkaline hydrolysis of sarin (GB) and soman (GD)**

## Hydrolysis

The possible dangers from toxic emissions at incineration facilities have produced a public aversion to this method. In consequence, alternate destruction technologies have been considered, such as the use of hydrolysis. Generally, hydrolysis is based on the reaction of agents with water. As nerve agents all contain a phosphorus (V) atom bound to a carbon atom, aqueous sodium hydroxide

Studies of the chemical hydrolysis of sarin and soman highlight the stability of the P-Me bond. In contrast and due to the absence of the P-Me bond, the total hydrolysis of tabun (GA) produces phosphoric acid (Figure 3).

The hydrolysis of nerve agents is remotely related to their mode of action in humans and animals, where inhibition of the enzyme acetylcholinesterase (AChE) occurs due to the formation of an adduct with the hydroxyl group of a serine



**Figure 3. Hydrolysis reaction of tabun (GA).**

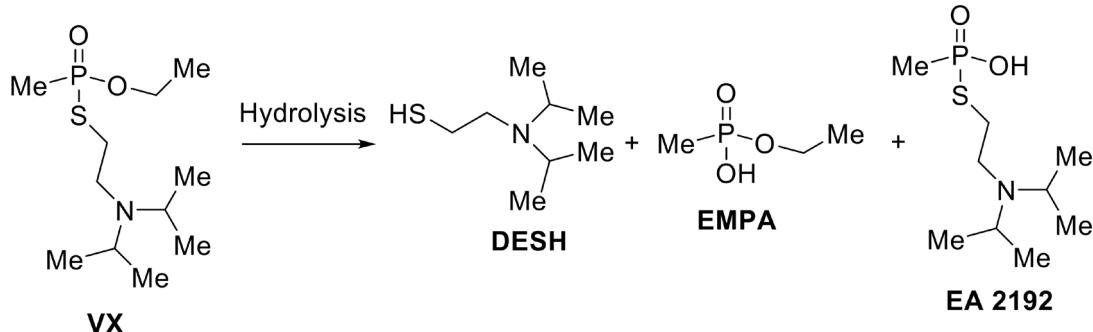
residue in the enzyme's catalytic center. This process is described in further detail in the article on biomedical sample analysis on page 18 of this issue.

The hydrolysis of VX with aqueous sodium hydroxide is a very complex process involving several pathways. A variety of products (Figure 4) can be formed depending on the pH and the temperature at which the hydrolysis occurs. The main products are *N,N*-diisopropylaminoethane-2-thiol (DESH), ethyl methylphosphonic acid (EMPA) and the toxic S-(2-diisopropylaminoethyl) methylphosphonothioic acid (EA-2192). DESH and EMPA are formed through P-S bond cleavage while EA-2192 is produced from P-O bond cleavage. Due to a lack of reactivity of EA-2192 toward further hydrolysis, this toxic by-product requires further heating in concentrated sodium hydroxide, to degrade to less toxic products.

## New approaches to hydrolysis technologies

Hydrolysis can also be combined with oxidative processes. Peroxides are adequate reactants for decontamination because they are non-toxic and not corrosive. Hydrogen peroxide and sodium perborate have been applied to the perhydrolysis of V and G agents. Oxidative chlorination using aqueous or solid bleach was first introduced during the First World War. Under perhydrolysis conditions, for example, sarin decomposes through P-F bond fission while VX undergoes an oxidative hydrolysis that breaks the P-S bond.

Several new approaches to hydrolysis have been investigated, including metal-based processes in both catalytic and non-catalysed reactions. Different options can be used depending on the metal center and the ligand involved. Electrochemical

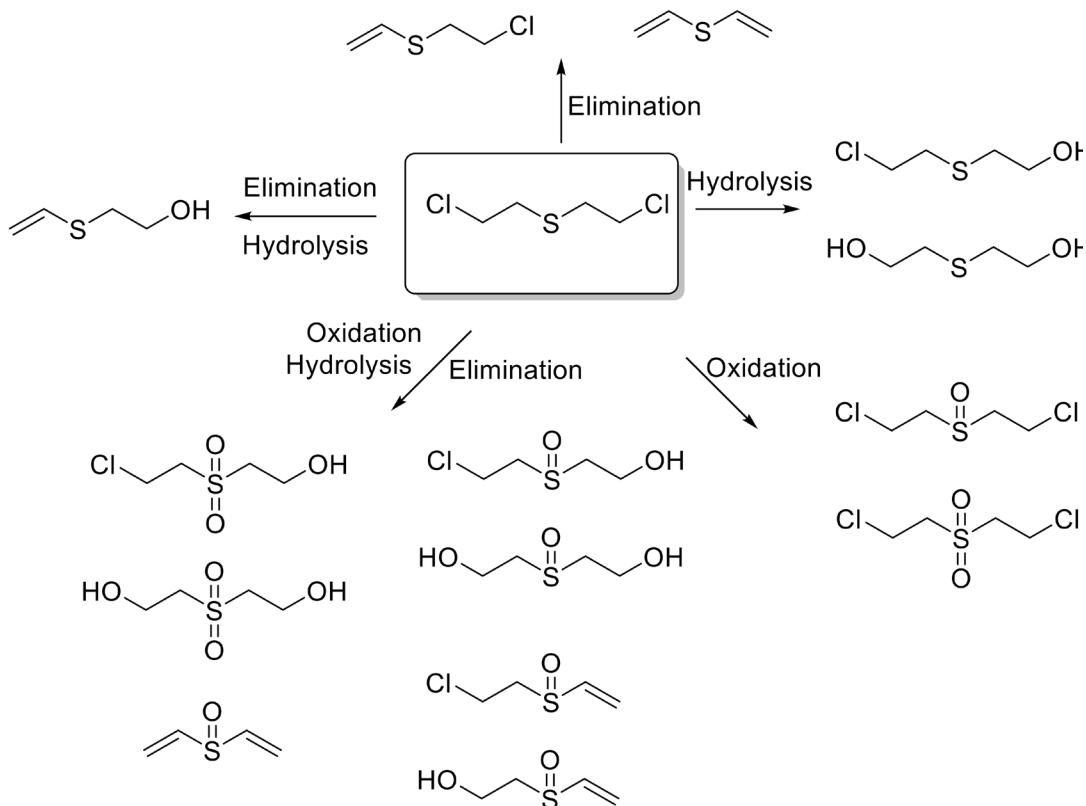


**Figure 4. Hydrolysis of VX.**

One of the most representative blister agents is sulfur mustard. In general sulfur mustards undergo a variety of processes, including oxidation, elimination and nucleophilic substitution when exposed to aqueous oxidative and basic media such as bleach and other decontaminants. Figure 5 illustrates the compounds formed when sulfur mustard (bis(2-chloroethylsulfide), HD) reacts under either hydrolytic or oxidative conditions. The main product of the sulfur mustard hydrolysis is thioglycol which can be further eliminated by microbial digestion.

oxidation using silver nitrate in concentrated nitric acid (that produces Ag<sup>2+</sup>) has been demonstrated to be a powerful oxidising system that can cleave organic molecules, although this process is technically very complex.

Supercritical water (SCW) can also be a medium for chemistry with many applications. Water exhibits unique properties when used above the thermodynamic critical point ( $T_c = 374^\circ\text{C}$ ,  $p_c = 22.1 \text{ MPa}$ ), where no phase boundaries exist. The solubility behaviour is reversed: organic molecules are soluble in SCW while salts



**Figure 5 Alkaline and oxidative hydrolysis of sulfur mustard**

precipitate out of solution. In 2003, neutralisation followed by supercritical water oxidation (SCWO) was selected for the destruction of chemical weapons.<sup>4</sup> After hydrolysis, the corresponding hydrolysate is submitted to a SCWO process where radicals such as HO<sup>•</sup> and HOO<sup>•</sup> promote the total oxidation of organic compounds to water, carbonate, sulfate, phosphate, and gaseous nitrogen-containing products. The disadvantage of this method is that it is corrosive to reaction chambers.

### Conclusions

Many chemical processes have been investigated for a rapid, cheap, clean and safe destruction of chemical weapons, but only a very small number of these methods have been applied to the destruction of large quantities of these agents.<sup>5</sup> Destruction facilities in the United States of America and the Russian Federation as well as the field-deployable systems being used by the UN-OPCW Joint Mission are all using hydrolysis technologies. The investigations of new methods based on enzymatic digestion of chemical weapon agents are currently being researched. The use of

microorganisms, specifically modified bacteria which could use the chemical weapon agents as nutrients to produce non-toxic byproducts, is another method that has been considered.

### References

1. Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction, Organisation for the Prohibition of Chemical Weapons, The Hague.
2. [www.opcw.org/our-work/demilitarisation/destruction-timelines/](http://www.opcw.org/our-work/demilitarisation/destruction-timelines/).
3. NRC, Recommendations for the disposal of chemical agents and munitions: National Academy Press: Washington, DC, 1994.
4. U.S. Army's Chemical Materials Agency, Richmond, KY.
5. For extensive reviews, please see: Yang, Y. C. *Chem. Rev.* 1992, **92**, 1729-1743 and Kim, Kibong, Tsay, Olga G.; Atwood, David A.; Churchill, David. G. *Chem. Rev.* 2011, **111**, 5345-5403.

# High Temperature Incineration

By Michelle Holmes, Communications Manager, Veolia

## Overview to the OPCW campaign

Veolia has safely treated 190 metric tonnes of chemicals removed from the Syrian Arab Republic at its Ellesmere Port high temperature incinerator (HTI). The facility is one of the most advanced of its type in Europe.<sup>1</sup> Veolia treated these chemicals under an existing contract with the British Government.

The destroyed chemicals consisted of primarily “B precursors” along with a small quantity of hydrochloric acid. The B precursors are industrial grade chemicals that can be used to produce nerve agents. The B precursors are chloramine compounds, similar to those that the plant treats routinely for the pharmaceutical industry.

The operation was carried out according to the stringent terms of an existing environmental permit with the Environment Agency that regularly inspects the site. In addition, the site was inspected independently by the OPCW and the Health and Safety Executive (HSE).

The 190 tonnes represent 0.15% of the chemicals treated at the site every year. These chemicals were completely destroyed by burning them at temperatures of up to 1,200°C under the supervision of OPCW inspectors as well as relevant UK regulatory authorities.

## Who is Veolia?

As the leading global environmental solutions provider, Veolia has an excellent track record and specialist expertise in delivering the most extensive range of recycling, recovery and disposal solutions.

Veolia is the largest provider of hazardous waste services in the UK. Its Ellesmere Port incinerator is a best-in-class facility with an existing hazardous waste treatment contract with the Disposal Services Authority (DSA), part of the Ministry of Defence.

Veolia offers the very best technical knowledge, support and specialist expertise along with the technology to make waste safe. Its HTI not only provides the highest levels of safe and secure destruction, it also offers outstanding environmental performance too.

## Introduction to the Veolia HTI

High temperature incineration provides the best overall environmental option for the clean and complete disposal of hazardous waste streams that cannot be sustainably recovered or recycled elsewhere.

The Veolia rotary kiln HTI is permitted to accept 100,000 tonnes of waste solids, sludges, liquids and gases per annum. Certified to the international quality standards for quality and environment, ISO9001, ISO14001 and OHSAS18001, its unique design enables the treatment of the widest range of hazardous, non-hazardous and low-level radioactive waste materials in Europe.

HTI is a proven solution for a wide range of hazardous wastes. The process destroys wastes at temperatures of up to 1,200°C to guarantee 99.99% thermal destruction efficiency.

## Schematic of Veolia's HTI in Ellesmere Port

Veolia's unique technological capabilities optimise the waste management service to ensure that the entire process is secure and environmentally safe.

The HTI operates to comprehensive waste acceptance criteria and strict site procedures. When waste arrives at the facility, it is checked, sampled and assessed against delivery schedules. A computerised bar code system then ensures that each consignment of waste is traceable throughout the entire disposal process.

The facility operates to exceptionally high levels of security

1- Shredder	11- Second Scrubbing Tower
2- Packaged Waste Conveyors	12- Hot Air Mixer/Mist Eliminator
3- Fume Extraction	13- Fabric Filter
4- Packaged Waste Hoist	14- Induced Draught Fan
5- Bulk Solids Hopper	15- Continuous Emission Monitoring
6- Rotary Kiln	16- Stack
7- Secondary Combustion Chamber	17- Water Tank
8- Gas-Gas Heat Exchanger (Recuperators)	18- Slag Discharger
9- Saturated Venturi	19- Ash Hopper
10- First Scrubbing Tower	

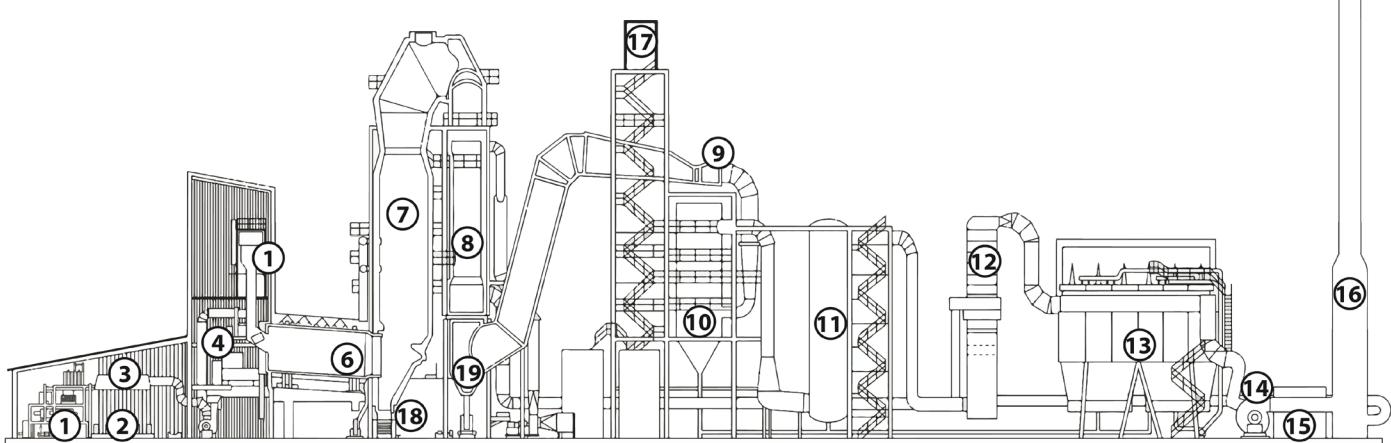


Figure: The high temperature incinerator at Ellesmere Port

and works closely with all relevant authorities including police, fire and rescue services.

## Technological Capabilities

The HTI can accept 100,000 tonnes of waste solid, sludges, powders, liquids, gases and halogenated wastes. This can be in the form of:

- Bulk and drummed liquids via a 15,000 te tank farm
- Oily sludges
- Contaminated soils and powders
- Pharmaceutical products
- Contaminated packaging and materials
- Highly sensitive and out-of-spec products
- Highly toxic, reactive or malodorous liquids or gases and bulk powders
- Low-level radioactive materials\* (via drums, IBCs and bulk tankers)

\*Full range of alpha, beta and gamma radionuclides

### i) The Rotary kiln (location 6 in figure above)

The HTI facility has an advanced, water-cooled rotary kiln to ensure the complete combustion of waste materials. Fully automated with computer-controlled waste feed mechanisms, it also features safety interlocks to disable the operation if necessary.

The kiln rotates between one and six revolutions per hour. This allows for a waste residence time of 30 to 90 minutes ensuring maximum burnout and volatilisation of organic materials.

The slag that is produced flows continuously into a water quench in the base of the secondary combustion chamber. It immediately cools to form an inert, glass-like solid.

### ii) Secondary combustion chamber (SCC, location 7 in figure above)

Exhaust gases from the kiln pass into the 25-meter high

SCC. Here, liquid wastes and air are added tangentially, creating a vortex. Separate lances then inject the aqueous, gaseous and non-compatible wastes.

The residence time in the SCC is more than two seconds after the last injection of air. Combined with turbulence, excess oxygen and a temperature of up to 1,200°C, this ensures the safe and highly efficient destruction and removal of all wastes.

### iii) Gas cleaning and scrubbing

Combustion gases leave the SCC and pass through a pair of parallel gas-gas heat exchangers (location 8 in the figure on page 15). These lower the temperature to around 800°C. The hot air produced at 300°C is then re-used later in the process to reheat flue gas. A water quench system then instantaneously reduces the temperature to less than 80°C. This rapid cooling also contributes to the plant's outstanding environmental performance.

The saturated gases are then passed through two scrubbing towers (locations 10 and 11 in the figure on page 15). These remove hydrochloric acid, oxides of sulphur, bromine and some of the inert particulate matter. The gases then enter a fabric filter. Lime is added to aid filtration and the final particulate and any residual acidity are removed.

### iv) Storage

The HTI has a 2000 m³ covered storage area for packaged solid wastes that are ready for incineration. This is equipped with automated, computer-monitored conveyors that transport waste to the kiln. All our drum storage and drum handling facilities are protected by foam deluge systems.

Our storage facilities include purpose-built areas for individual waste types. These include nitrogen blanketed liquid storage tanks protected by a water deluge system with a total capacity of 14,570 m³.

## Safety and security

The incinerator at Ellesmere Port is a permitted facility, regulated by the Environment Agency to ensure environmental performance well within agreed limits. It fully complies with this strict environmental permit and operates well within the prescribed limits. Environmental performance is constantly monitored and independently verified.

It has also passed five separate inspections by the OPCW in addition to HSE inspections. The chemicals originating in the Syrian Arab Republic are standard industrial chemicals the likes of which are routinely destroyed at this facility. The destruction proceeded under the purview of the site's existing environmental permit to high environmental, health and safety standards.

The HTI is authorised under the Integrated Pollution, Prevention and Control (IPPC) provisions of the 1990 Environmental Protection Act. It complies fully with the Waste Incineration and Industrial Emissions Directives and is certified to the international quality and environment standards. The facility's EPR10 permit also allows it to handle a full range of low-level radioactive materials.

Compliance is central to everything the HTI does. Its highly trained team has an excellent health and safety record and consistently over-performs when it comes to meeting strict emissions limits. The design of the HTI includes the very latest solutions in incineration and gas cleaning technology. Coupled with some of the world's most sophisticated monitoring, control and operating systems, it ensures safety and environmental protection as required by the CWC for the destruction of chemicals.

## Reference

1. [www.opcw.org/news/article/ellesmere-port-facility-completes-destruction-of-its-consignment-of-syrian-chemicals-almost-three-q/](http://www.opcw.org/news/article/ellesmere-port-facility-completes-destruction-of-its-consignment-of-syrian-chemicals-almost-three-q/)

# The Temporary Working Group on Verification

By Professor Roberto Martínez Álvarez

**W**ith a view to tackling verification-related issues with scientific and technological dimensions that have arisen over recent years, the Director-General of the OPCW decided in 2013 to establish the Temporary Working Group (TWG) on Verification, under the leadership of the Scientific Advisory Board (SAB), for a period of up to three years. Three meetings have been held so far: in March and September 2013 and in April 2014.

The main objective of the TWG on Verification is to consider scientific and technological elements of verification technologies and methodologies, emerging technologies and new equipment.

The TWG consists of SAB members and other experts in the theory and practice of verification. The collective expertise of this TWG includes chemical weapons and industry verification, implementation of the Chemical Weapons Convention (CWC) and implementation of other relevant international treaties.

As part of its mandate, the TWG on Verification is examining whether technologies and methodologies used in other international treaties could benefit the CWC regime. In this regard, the TWG has received briefings on relevant approaches in the International Atomic Energy Agency (IAEA), the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), the Organization for Economic Co-operation and Development (OECD) and the World Health Organization (WHO). The TWG has also heard perspectives relevant to the Biological Weapons Convention.

Some of the findings in the final report of the Temporary Working Group on the Convergence in Chemistry and Biology form part of the basis for the discussions

of the TWG on Verification, for example, the SAB's recommendation that "any process designed for the formation of a chemical substance should be covered by the term *produced by synthesis*".

The TWG on Verification is also considering possible improvements in sampling and analysis during on-site inspections together with the new technologies that can add values to the current capabilities. In this regard the results of the analyses carried out with the samples collected in the 2013 investigation highlighted the importance of continuing to build capacity for analyses of environmental and biomedical samples.

It is expected that this TWG will conclude its work during 2015, reporting to the Twenty-Second or Twenty-Third Session of the SAB.



**Professor Roberto Martínez Álvarez (of Spain) is the head of the department of organic chemistry at Complutense University in Madrid. Professor Martínez Álvarez is a member of the OPCW Scientific Advisory Board and serves as Chair of the TWG on verification. His areas of expertise include organic synthesis of heterocyclic systems, mass spectrometry, and nuclear magnetic resonance.**

# Conducting Analysis of Biomedical Samples to Assess Exposure to Organophosphorus Nerve Agents

Contribution from the OPCW Laboratory

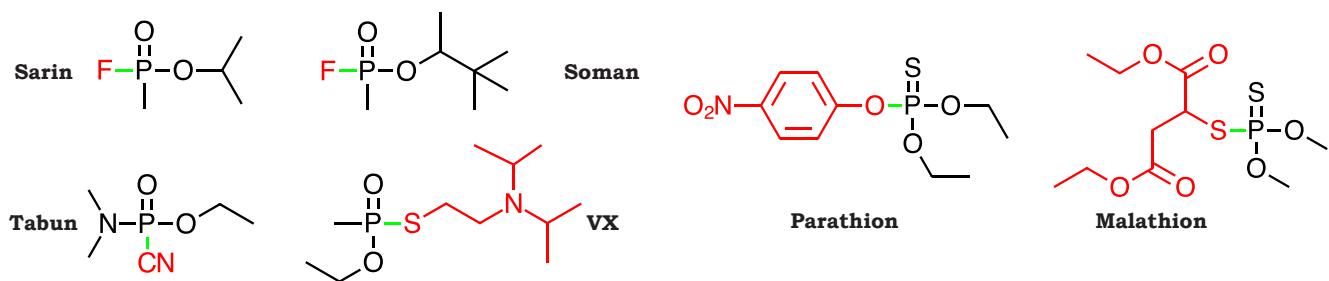
## 1. INTRODUCTION

Highly toxic nerve agents such as tabun, sarin, soman and VX are banned under the Chemical Weapons Convention (CWC) and formed major parts of large stockpiles of chemical weapons during the Cold War. Terrorist attacks carried out by the cult Aum Shinrikyo in Japan in 1994 and 1995 employed sarin. The OPCW-supported UN mission that investigated the August 2013 chemical attacks in Ghouta, Syria, determined that the chemical agent used was also sarin.

Sampling and analysis of environmental samples can reveal the presence or absence of these agents (and/or their degradation products) but in order to assess if a potential victim was exposed, the analysis of biomedical samples is required. Blood and urine samples are preferred as they are easily collected, but the analysis of body tissues is also possible. Tissue samples are especially relevant in case of deceased individuals.

## 2. NERVE AGENTS - CHEMISTRY AND STRUCTURE

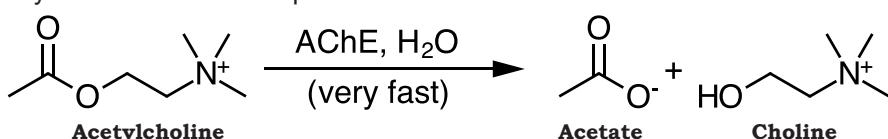
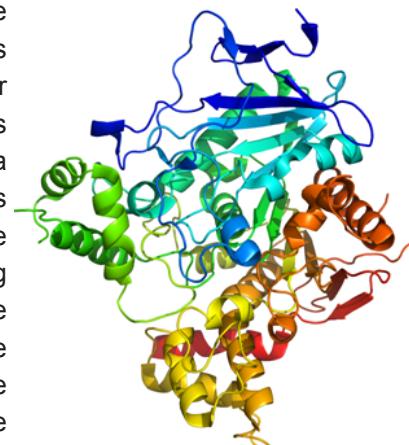
Nerve agents are organophosphorus compounds and are liquid at room temperature. For understanding their reactions in the human body it is helpful to introduce the concept that the molecules are made up by two different parts (see below). First is the phosphorus-containing part (shown in black) in which a phosphoryl group ( $P=O$ ) is bonded to an O-alkyl (-O-R) group and a short alkyl group (R) or a small dialkylamino group (-NR<sub>2</sub>) in case of tabun. The other part of the molecule is the so-called “leaving group” (shown in red). In case of sarin and soman this is a fluorine atom (-F), in case of tabun a cyano group (-CN), and in case of VX a larger group containing nitrogen and sulphur. Most relevant reactions of the agents involve the chemical bond connecting these two groups (shown in green).



Organophosphorus pesticides are similar in structure (nerve agents were found while looking for new effective pesticides) and mode of action. Parathion and malathion are shown as examples above. The substitution of oxygen in the phosphoryl group with sulphur lowers toxicity for humans.

### 3. ACETYLCHOLINESTERASE - THE TARGET

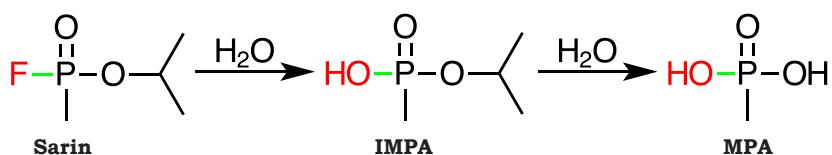
The primary toxicity of nerve agents is due to their ability to inhibit the action of an enzyme (protein with catalytic activity) crucial in the process of conducting nerve signals. Acetylcholinesterase (AChE) is responsible for the breakdown of the neurotransmitter acetylcholine at neuronal junctions by hydrolysis (reaction with water, see reaction scheme below). In a simplified view this switches a nerve signal from on to off. If the enzyme is blocked, acetylcholine will accumulate and signal transmission cannot be terminated. This leads to cholinergic crisis and typical symptoms including sweating, salivation, miosis (pinpoint pupils), paralysis, respiratory failure and eventually death. Because AChE is a very fast and efficient enzyme (one enzyme molecule can break down 25,000 molecules of acetylcholine per second) and is not present in very large amounts, blocking of the enzyme quickly leads to fatal consequences.



Human AChE consists of 640 amino acids. In the human body most of the AChE is found as units of two (dimer) or four (tetramer) AChE molecules that are anchored to a membrane. The picture above shows the complicated folding of the protein leading to its three-dimensional structure. Helical substructures and so-called beta-sheets (shown as thick arrows) can be identified. The catalytic active site is buried deep inside the enzyme. It contains three amino acids crucial for catalytic activity: serine 200, histidine 440 and glutamate 327. The nerve agents attach to serine 200 to block the enzyme. Inhibited AChE is shown on the front cover of this issue.

### 4. ANALYSIS OF METABOLITES

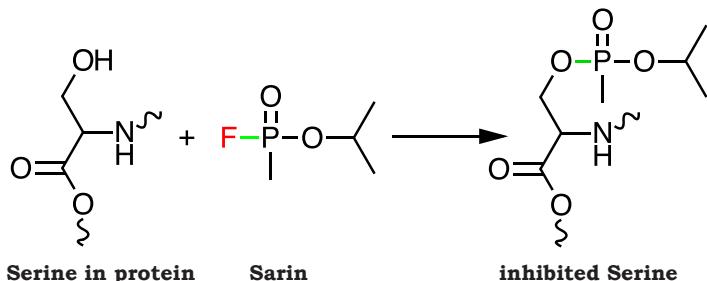
Nerve agents that are not interacting with AChE or other proteins in the human body (see below) normally hydrolyse quite rapidly. This is especially the case for hydrophilic agents such as sarin while lipophilic agents such as VX can form depots of intact agent in fatty tissues. In case of sarin, the primary hydrolysis product (which is unable to block AChE) is isopropyl methylphosphonic acid (IMPA) that can further degrade to methylphosphonic acid (MPA). Other indicators for the presence of the agent are typical side-products formed during sarin synthesis, such as diisopropyl methylphosphonate (DIMP).



These compounds can be detected in urine and blood samples using liquid or gas chromatography. Due to the low concentrations in body fluids (in the parts per billion range) GC-MS/MS or LC-MS/MS methods employing single ion monitoring (SIM) or multiple reaction monitoring (MRM) modes are commonly used. This requires targeted analysis, meaning that one has to specifically analyse for a specific compound such as IMPA.

## 5. PROTEIN ADDUCTS AND THEIR FATES

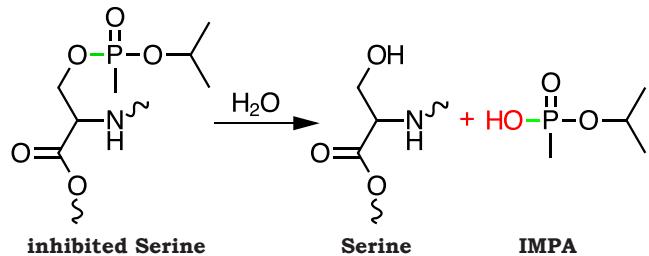
Nerve agents do not only react with AChE but also with other proteins. One highly similar to AChE is butyrylcholinesterase (BChE). In contrast to the membrane anchored AChE, BChE is found in blood serum and can be used for analysis more easily. The active site of BChE also contains a catalytic triad of serine, histidine and glutamate, and the molecular mechanism of inhibition is identical with AChE, with the agent attaching itself to the serine residue. During this reaction the leaving group is lost. (Note that serine is the name of an amino acid—the name originating from the fact that it was first isolated from silk glue (sericum in Latin)—and it is completely unrelated to the nerve agent sarin.)



After the attachment of the agent to the serine residue, the enzyme is blocked and cannot perform its normal activity. This primary protein adduct can react further in a number of ways, described as follows.

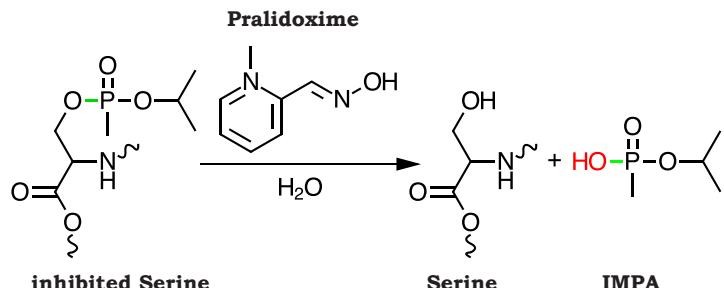
### *Spontaneous reactivation*

The inhibited serine might react with water to produce the original and functional serine residue plus the hydrolysis product of the agent (IMPA in case of sarin). While this process plays a role for certain pesticides, it is too slow to be of relevance in case of nerve agent poisoning.



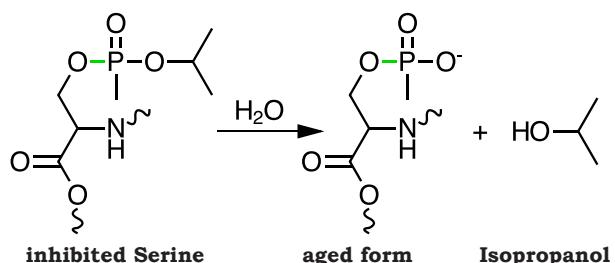
### *Reactivation with a nucleophile*

Nucleophilic compounds such as oximes can be used for induced reactivation. Such oximes are commonly used as therapeutics in case of nerve agent poisoning. They include compounds such as 2-PAM (pralidoxime), obidoxime, HI-6, MMB-4 and TMB-4.



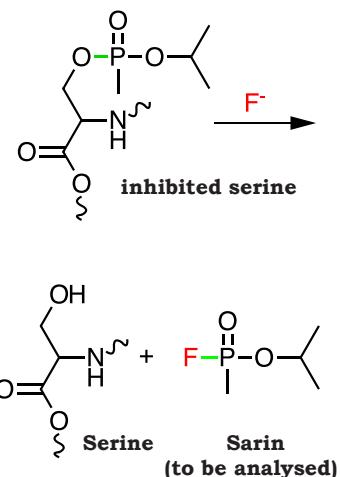
### *Ageing*

The inhibited serine can lose an additional group from the phosphorus atom leading to a structure with a negative charge at an oxygen connected to the phosphorus (a process called ageing). This structure cannot be reactivated using oximes. While some agents age relatively slowly (over hours and days) others are much faster. Soman ages within minutes, making medical therapy even more difficult.



## 6. FLUORIDE REACTIVATION

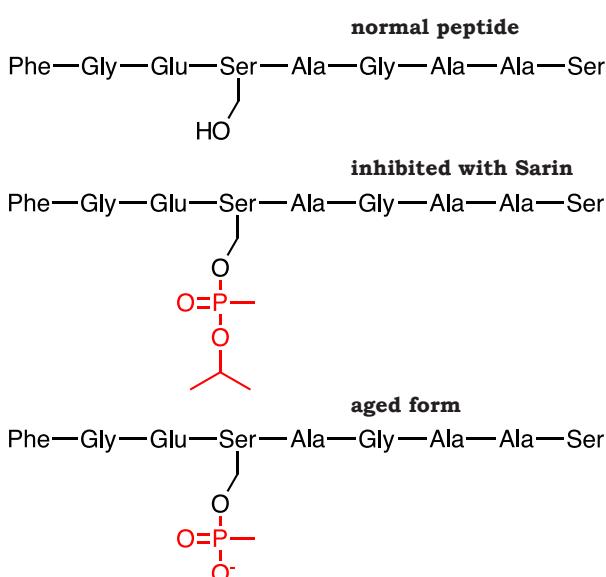
One advantage of analysing protein adducts over free metabolites in blood is that they persist for much longer times. While free metabolites are cleared from blood in a couple of days, protein adducts may persist for several weeks. One approach for analysis that does not require a look at large protein molecules or fragments is fluoride regeneration. Sodium fluoride solution is added to the blood or plasma sample and the fluoride ions react with the protein adducts to release the agent again. In case of sarin, soman and cyclosarin, the original agent is regenerated. In case of tabun, fluorotabun is produced and in case of VX the product of fluoride regeneration is ethylsarin. The one problem that exists with this procedure is that aged protein does not react with fluoride and these molecules escape detection.



## 7. DIRECT ANALYSIS OF ADDUCTS

When a nerve agent binds to AChE or BChE there is a characteristic mass change in the protein that can be used to identify the agent. The established procedure is relying on BChE in human blood plasma. Instead of using the intact protein (consisting of 574 amino acids) the protein is cut into smaller pieces (so-called peptides) by using the digestive enzyme pepsin. The fragment of interest is a peptide of nine amino acids that contains the serine residue inhibited by nerve agents.

The different peptides generated by the pepsin digest are separated using liquid chromatography (LC) and analysed using tandem mass spectrometry (MS/MS). As the leaving group of the agent is lost when binding to AChE or BChE, this analysis cannot reveal the absolute identity of the agent used (the same is true for fluoride regeneration and any other analysis that does not identify the intact agent). For example, an adduct that is identical to the one produced upon exposure to sarin might actually come from an agent that featured a leaving group similar to that of VX. Aged adducts contain less information, but these peptides contain more information than just finding free MPA, as MPA is also a degradation product of some legitimate chemicals such as the flame retardant dimethyl methylphosphonate (DMMP). The aged adduct is clear proof that the body was exposed to a toxic methyl-phosphonic chemical that is able to bind to and block AChE and BChE. DMMP, for example, is unable to do this.



An alternative source for protein adducts is serum albumin. After digestion with pronase, adducts with the amino acid tyrosine can be detected.

# Secure Information Exchange (SIX) Project

When we speak of science and technology, we often limit our considerations to the traditional laboratory sciences of chemistry, biology, and physics. However, in our twenty-first century world, information and communication technologies are enabling much of the rapid advances we see across all scientific fields. Such technologies are likewise making their mark in our verification regime.

## The need for secure information exchange

Member States of the Organisation for the Prohibition of Chemical Weapons (OPCW) have declaration obligations stipulated under various articles of the Chemical Weapons Convention. These declarations could contain confidential information and the only channel available so far for the exchange of such information between the Member States and the Technical Secretariat (TS) has been the physical exchange of information through the Permanent Representatives of the Member States. This procedure imposes certain logistical difficulties which can cause delays and may, therefore, adversely impact important activities of the Secretariat, such as the timely evaluation of declarations and the planning of inspections.

From a survey concluded in 2012 it was found that the Member States depend on the diplomatic pouch for the exchange of confidential information between their National Authorities and their Permanent Representatives in The Hague or in Brussels, who would then hand deliver the information to the TS. The travel time for the diplomatic pouch varies depending on the geographical distance, and the frequency and the route of the diplomatic pouch, which may travel to other capitals before arriving in The Hague. The survey results also highlighted that the National Authorities would welcome and support an alternative secure electronic channel that can facilitate exchange of information using the Internet.

## A twenty-first century solution

Subsequently, having reviewed the technical, legal and security aspects of such a mechanism, the TS initiated

the Secure Information Exchange (SIX) project. The purpose of the project was to establish an end-to-end solution enabling the secure exchange of information between States Parties and the Secretariat - using the Internet, incurring minimal additional cost and leveraging the existing infrastructure and established procedures.

A more detailed analysis was conducted on technical, security and legal aspects of the project. The TS liaised with other international organisations which have implemented a similar mechanism, briefed the Member States on a regular basis and successfully completed a pilot programme with the participation of 10 Member States from different regional groups.

To provide assurance in respect of the level of security offered by the system, there were security assessments and audits conducted for the overall system (both for the technical implementation and the operating procedures). The TS has successfully implemented recommendations emanating from these audits and the system is now available to the State Parties.

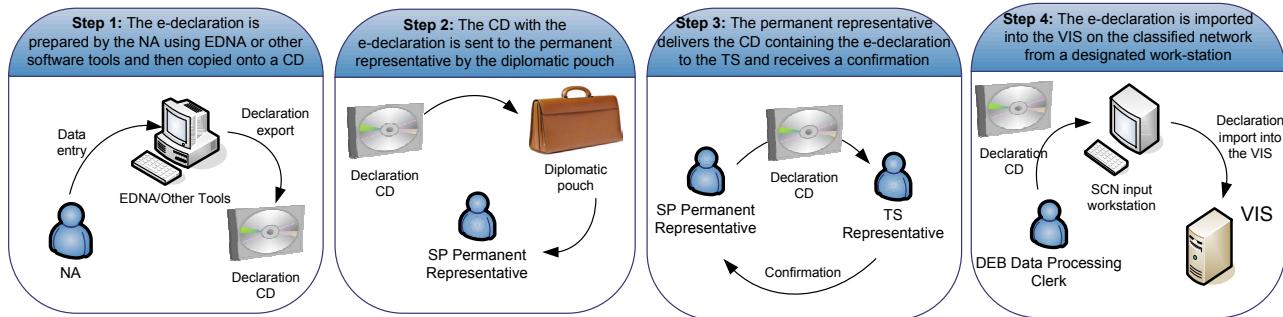
## How it works

The SIX system is composed of two main components:

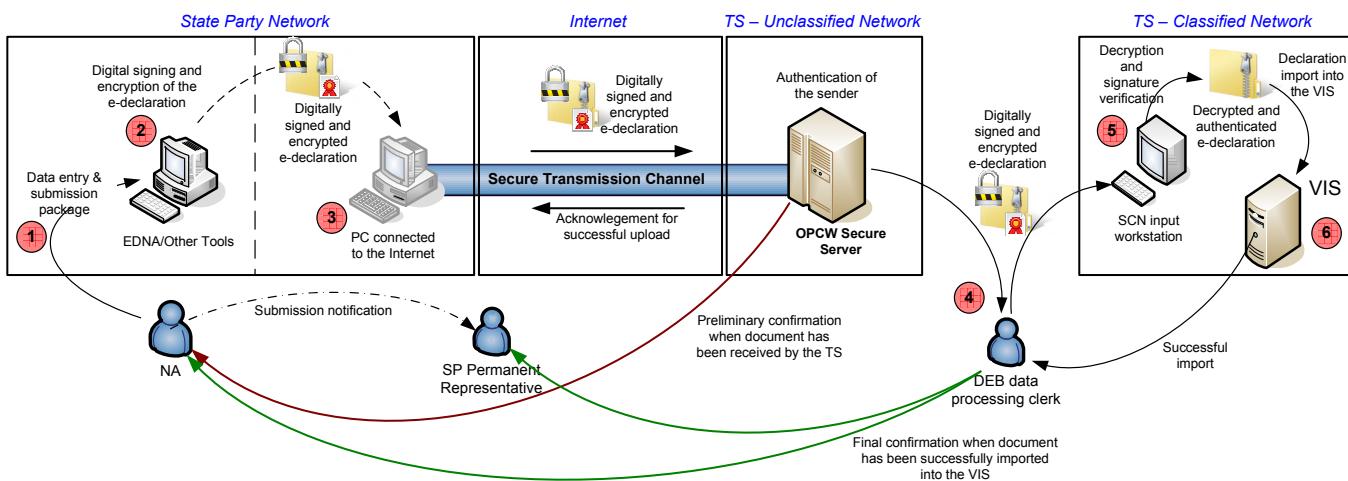
1. A secure web-based software application, which has been acquired, installed, configured by the TS, and will be accessible to authorised users from the State Party (SP) at no cost using a standard web browser, without any need to have additional software applications installed. This commercial software application is physically hosted at the TS and secured by the TS's network infrastructure. It will also be maintained by the TS.
2. A software tool for the encryption and decryption of data, which is to be acquired and utilised by the SPs that are interested in using the system for the exchange of information. The selection of the actual tool will be up to the individual SP as long as the preferred tool supports a widely used encryption standard called OpenPGP. There are free, "open-source" tools available at no cost, as well as commercial ones.

## Transmission of Electronic Declarations for Article VI

### Current way of transmission



### Proposed way using electronic transmission



The TS issued a note (S/1192/2014, dated 1 July 2014) on the availability of the system, the terms and conditions that will govern its use and the next steps for the SPs that are interested in using the system.

In the next phase, the SIX project team will work closely with the National Authorities, the Permanent Representatives, and technical experts of the Member States interested in utilising the new system.

Furthermore, the TS has provided guidelines to the States Parties on how to set up the system based on a common encryption tool and to generate cryptographic keys as well as information security best practices on how to safeguard the components of the system to ensure security.

### Benefits

The following direct benefits are expected from the full

implementation of the SIX system:

- Improvements in the timeliness of declarations:
  - A measurable efficiency gain with declarations being transmitted in minutes rather than weeks;
- Increased efficiency in the processing and evaluation of declarations by using the same channel for:
  - Submission of the requests for clarification from the TS to Member States;
  - Submission of declaration amendments;
- Overall improvements to the verification process:
  - Automated notifications of receipt to the National Authorities and to the Permanent Representatives;
  - A reduction in the number of communications to be picked up from the OPCW Headquarters and subsequent reminders in case of delays in collecting such communications;

- A reduction in security incidents attributable to the transmission of confidential data through inappropriate means;
- Support and motivation for Member States to transition to electronic declarations;
- Motivation for a future potential transmission channel for other confidential information transmitted between the TS and the Member States;
- Motivation for a future potential channel for the

multilateral exchange of information between the States Parties (e.g. for collaborative work in order to resolve transfer discrepancies).

The TS will continue to work with the Member States and identify other business processes where the use of the SIX system can introduce improvements and efficiency.

Further information about SIX can be found through the “SIX Documents” link on the OPCW external server home page. You can also contact the project team directly, by e-mail at [six@opcw.org](mailto:six@opcw.org).



**Children of OPCW staff members having fun learning chemistry at the “Peace of Art” event on 27 May 2014**



**Inspector training**

# The Temporary Working Group on the Convergence of Chemistry and Biology

By William Kane

In recent years, there has been increasing interest in how rapid advances in the life sciences (including the convergence of chemistry and biology) might affect implementation of the Chemical Weapons Convention. This has included recognition that some of these developments have the potential to be misused; for example, the use of biologically mediated processes for the production of toxic chemicals, toxins or bio-regulators.

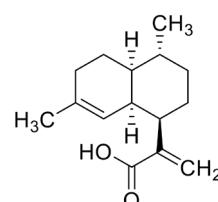
To study this matter in more detail, the Director-General established the Temporary Working Group (TWG) on the Convergence of Chemistry and Biology in 2011. To meet the TWG's objectives, experts from a broad range of backgrounds that included industrial and academic scientists, defense laboratory scientists, toxicologists, analytical chemists and chemical engineers (including those with experience in bio-mediated processes) were appointed. The expertise of the TWG was complemented with guest speakers, whose experience covered commercial biotechnology, synthetic biology, informatics, and "do-it-yourself" (DIY) biology. The TWG held four meetings over a two-year period and has issued its final report with recommendations to the Director-General, (SAB/REP/1/14, dated 27 June 2014).<sup>1</sup>

Advances in biological production processes and their commercial applications are increasing and indeed one might say they are a "moving target". Use of enabling technologies such as high-speed computing and high-throughput screening are being used more routinely to speed up research and development. Additionally, the use of multidisciplinary teams (with expertise in chemistry, biology, engineering, physics, mathematics, computer science, etc.) has become more common – when teamwork is combined with enabling technologies, more can be accomplished with fewer human resources in a shorter time frame.

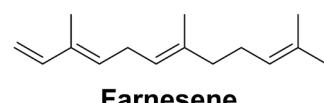
With this rapid pace of change in mind, the TWG could only take a "snap shot" of the current biotechnology activity and trends. A number of the TWG's recommendations reflect this reality and call for the continued monitoring of biotechnology advances and related commercial

applications relevant to the CWC.

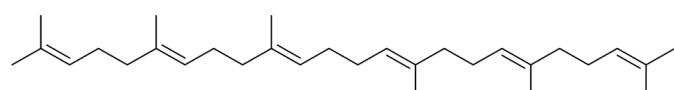
The biotechnology industry has some overlap with the chemical industry. This is because high yield bio-mediated production processes are being developed and commercialised for large scale production of chemicals. This includes the use of advanced fermentation processes and the use of engineered enzymes to convert biomass feedstocks to basic and fine chemicals. A number of bio-based processes have become competitive with conventional fossil fuel based processes as advances in biotechnology, such as metabolic engineering, have been realised. The availability of renewable biomass feedstocks, such as corn, grain and plant sugars, provide key economic and environmental drivers for these new commercial processes.



**Artemisinic Acid**



**Farnesene**



**Squalene**

Production of more complex organic molecules is also now a reality using custom designed biological processes and synthetic biology platforms. As an example, there is a new large scale production facility that started up in 2012 producing farnesene (see molecular structure above), a C15 terpenoid chemical. Farnesene is used as a building block for more complex chemicals such as squalene and artemisinic acid (an antimalarial drug intermediate).

The increasing use of biologically mediated production processes has implications for the Chemical Weapons

Convention verification regime. The TWG has reviewed the meaning of the term “produced by synthesis” as it applies to Part IX of the Verification Annex of the Convention, in the context of declarations required for OCPFs (other chemical production facilities). The view of the TWG was that any process designed for the formation of a chemical substance should be covered by the term “produced by synthesis”. Further assessment is needed of the new bio-based production facilities to determine their degree of relevance to the object and purpose of the CWC.

The TWG assessed the potential applications to produce classical chemical warfare agents such as nerve agents and blister agents. It concluded that there is no currently known advantage in trying to produce such chemicals through biological means. Scaling up a new biological process takes considerable investment of capital, resources and time; these considerations could reduce the likelihood of using such methods for large scale production of chemicals of concern, however, bio-mediated processes might still be effective for producing small quantities of toxins that are lethal to adult humans in microgram or lower dosage.

The convergence of chemistry and biology is providing major benefits to humankind, particularly in health care, alternative energy sources, and in environmental control. Combined with other advances, particularly in nanotechnology, it is also being utilised in the development of improved defensive countermeasures against chemical and biological warfare agents that could have implications for verification and assistance and protection against chemical weapons. There have been beneficial developments as well in protective clothing and equipment, decontamination, verification, detection/diagnostics, and medical countermeasures.

A number of recommendations were made to the Director-General taking into consideration the rapid advances in biological processes and their commercial applications. In particular, it was recommended that the Scientific Advisory Board (SAB) and the Technical Secretariat should continue to monitor such advances as well as new production technologies related to convergence. It will also be important to assess the relevance of these advances to verification under the CWC. Also, advances in systems, synthetic biology, and nanotechnology, which have enormous potential for beneficial applications, should be monitored.

With continued convergence of chemistry and biology, the TWG also recommended that a structured approach to maintaining contacts with the Biological Weapons Convention community should be established. Existing relationships should be further developed to bring together technical expertise in areas of common interest.

The TWG also noted that convergence of chemistry, biology and other sciences is a technically complex area, and consideration should be given to the development of outreach material to assist staff at States Parties permanent missions to the OPCW in understanding possible implications for the CWC.

Finally, with the rapid pace of advances, consideration should be given to re-activating the TWG on Convergence periodically, e.g. every five years prior to the SAB report to the Director-General on science and technology (S&T). In other words, taking another “snap shot” of the convergence of chemistry and biology will be an excellent way to keep up with future technical developments and their implications to the CWC – as was just done by the current Convergence TWG.



**William Kane (of the United States of America)** is a member of the OPCW Scientific Advisory Board and served as Chair of the Temporary Working Group on the Convergence of Chemistry and Biology from its second until its final meeting. Mr Kane has extensive technical and managerial chemical plant experience. His areas of expertise include the implementation of the Chemical Weapons Convention, chemical production practices and scale-up/start-up of new chemical processes.

## Reference

1. This report can be obtained from the OPCW website at: [www.opcw.org/index.php?eID=dam\\_frontend\\_push&docID=17438](http://www.opcw.org/index.php?eID=dam_frontend_push&docID=17438)

# Featured Peer-Reviewed Article: Plants as Nerve Agent Detectors

By Matthew J. Baker, Matthew R. Gravett, Farrha B. Hopkins, D. G. Cerys Rees, James R. Riches, Adam J. Self, Andrew J. Webb, Christopher M. Timperley



There has been increasing interest in how rapid advances in the life sciences, including the convergence of chemistry and biology, might affect implementation of the Chemical Weapons Convention (CWC)<sup>1</sup>. Here we describe how increased knowledge of chemistry and biology, specifically the interaction of organophosphorus nerve agents with plants, might be useful in investigations of alleged use of such substances. We also describe briefly how plants might be used to remediate land contaminated by the nerve agents.

## Introduction

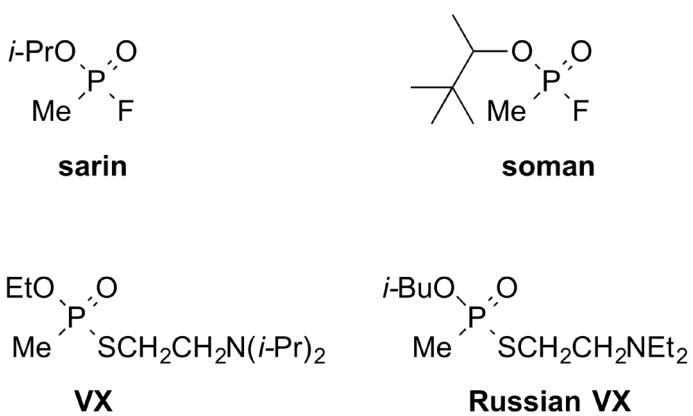
The Chemical Weapons Convention (CWC) prohibits the development, production, acquisition, stockpiling, retention, transfer or use of chemical weapons by Member States.<sup>2</sup> Verification of compliance and investigations into alleged use require accurate detection of chemical warfare agents (CWAs) and their degradation products. The ability of designated national laboratories to identify CWAs, their precursors and degradation products, at concentrations ranging from neat material to parts per billion, is essential in support of the CWC. The Defence Science and Technology Laboratory (Dstl) at Porton Down, where the authors work, houses the UK designated laboratory and has received the maximum 'A grade' in seven consecutive proficiency tests organised by the OPCW. Within this laboratory, detection of CWAs can be accomplished by analysing biomedical samples from casualties<sup>3-5</sup> and/or environmental samples.<sup>6,7</sup> Gas chromatography (GC) and liquid chromatography (LC), combined with mass spectrometry (MS), are the main techniques for the identification of nerve agents and related compounds, due to the requisite combination of high selectivity and sensitivity. The less sensitive technique of nuclear magnetic resonance spectroscopy, which helps the assignment of chemical structure, is sometimes employed in parallel,<sup>7</sup> but only for environmental samples where the quantity of sample is less restrictive, and the concentration of analytes present greater, than in the case of biomedical samples.

The nerve agents are divided into two classes based on their structures: German agents (G-agents) and venomous agents (V-agents) (Figure 1).<sup>8</sup> Most of the former contain a chemically reactive phosphorus-fluorine (P-F) bond and the latter a phosphorus-sulfur (P-S) bond. The G-agents

include sarin and soman, developed during World War II, and the V-agents VX and Russian VX, stockpiled during the Cold War.<sup>9-13</sup> Both classes are lethal in small doses. They inhibit irreversibly the enzyme acetylcholinesterase (AChE) which mediates nerve impulse transmission in the body. Its inhibition causes the toxic signs typical of nerve agents: convulsions, paralysis, and often death in the absence of medical treatment. Inhibition occurs through the nerve agent reacting with a specific amino acid (serine) in the enzyme active site through P-F or P-S bond cleavage.

Nerve agents react with water in the environment to generate harmless products – isopropyl methylphosphonic acid (iPMPA), pinacolyl methylphosphonic acid (PMPA), and ethyl methylphosphonic acid (EMPA) in the case of sarin, soman, and VX respectively – and then more slowly to methylphosphonic acid (MPA) (Figure 2).<sup>14</sup> These 'hydrolysis products' are water-soluble and aqueous solutions containing them can be concentrated to dryness and the residue treated with chemical reagents to convert the involatile iPMPA, PMPA, EMPA and MPA to volatile derivatives (a process called 'derivatisation')<sup>15</sup> to allow carriage by an inert gas into the GC-MS instrument to give a peak whose retention time and fragmentation pattern are characteristic.

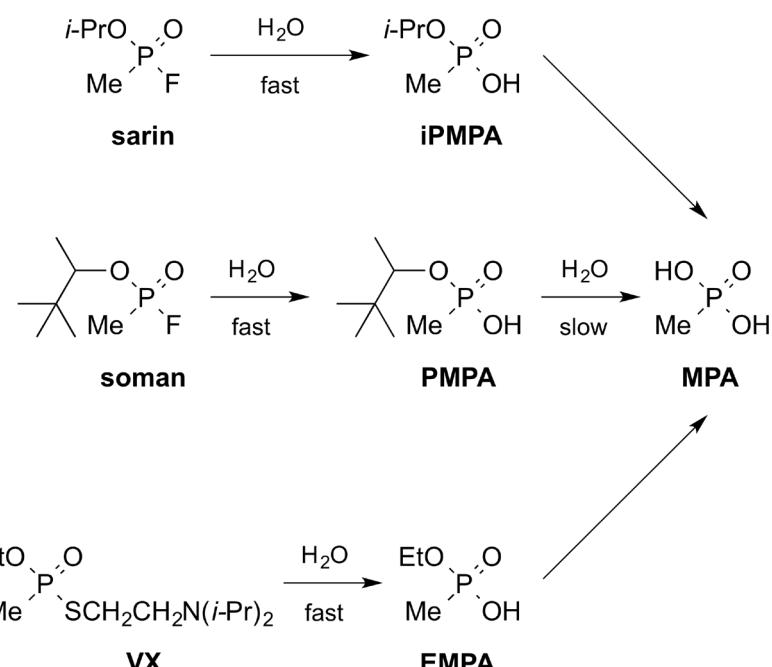
Additionally, the hydrolysis products can be analysed without derivatisation, by LC-MS, where the compounds under scrutiny elute in order of polarity in a solution of an organic solvent (e.g. acetonitrile) and water. When pure, iPMPA, PMPA, EMPA and MPA dissolve in water and have negligible toxicity. While iPMPA, PMPA and EMPA are liquids that are prepared by chemical synthesis,<sup>16,17</sup> MPA is a solid that is available commercially. These 'authentic standards' can be used to confirm unambiguously the presence of the compounds in the analysed samples.



G-agents

V-agents

**Figure 1. Some G- and V-agents.** Sarin and soman are volatile, and VX and Russian VX are involatile, liquids at ambient temperature. Destruction of the US and Russian stockpiles of, respectively, VX and Russian VX is under way and being monitored by the OPCW.



**Figure 2.** The nerve agents sarin, soman, and VX react with moisture in the environment to provide iPMPA, PMPA, or EMPA. These acids react slowly with water with loss of isopropanol, pinacolyl alcohol, or ethanol to provide MPA. It was the discovery of sarin, iPMPA and MPA collectively by OPCW designated laboratories, from analysis of samples collected by the UN investigating team after the 21 August 2013 attack in Ghouta, in the Syrian Arab Republic, that confirmed sarin-filled rockets had been used.<sup>7</sup>

## Environmental samples

Hydrolysis of nerve agents occurs in environmental matrices exposed to water.<sup>18–21</sup> Soil from alleged attack sites is normally the main matrix sampled. Other matrices can retain intact nerve agent through absorption and protection from atmospheric moisture, and analysis can help reconstruct an incident. Other matrices for sampling include metal fragments, polymeric materials such as plastics or rubber, and building debris. Soil samples taken four years after a sarin attack on a Kurdish population in the Iraq-Iran conflict were shown to contain iPMPA and MPA, and a metal fragment coated with military-type paint contained detectable amounts of sarin.<sup>3</sup> The UN investigation of the Ghouta sarin attack last year also reported iPMPA in a soil sample, and iPMPA and MPA on a metal fragment.<sup>7</sup> These types of products together comprise strong indicators of nerve agent use: no known pesticides contain the phosphorus-methyl (P-Me) bond found in the nerve agents, which is extremely stable (MPA remains unchanged when heated in concentrated nitric acid in a sealed tube<sup>22</sup>). It is therefore unsurprising that breakdown products found in the environment contain this characteristic and resilient bond. Such compounds do not usually occur in the environment naturally and certainly not in association with one another. Detection of iPMPA and MPA, or other such acids (e.g. PMPA or EMPA) and MPA, especially identified together with the nerve agent and/or production impurities possessing the P-Me bond, constitute compelling evidence of nerve agent use. Thus,

in cases where this is suspected, it is unnecessary to have a control sample of soil from an area thought free of contamination, to compare with that from the site of an alleged attack, as the likelihood of P-Me chemicals being present in any control sample is assumed, for the reasons outlined, to be zero.

## Sampling strategies

Sampling strategies for maximising the probability of discovery of CWA use are determined by the nature of the event and the area requiring sampling. There is no universal guide to where best to sample and decisions are made on a case-by-case basis, considering eyewitness and media reporting. Detection, identification and monitoring (DIM) equipment – point, stand-off or remote chemical agent detectors – can be used to indicate contaminated areas suitable for sampling. Molecular evidence will be abundant at the point of impact, on weapon fragments or in soil.<sup>3</sup> Can such evidence be destroyed by decontamination and/or fire? Decontamination leaves its own signature.<sup>23</sup> A recent study of VX on sand, burnt by ignited kerosene, or soaked beforehand with aqueous bleach or DS-2 decontaminant and then burnt, showed clearly that such harsh treatment did not destroy the VX and related impurities.<sup>24</sup> It can be concluded that attempts to destroy evidence of nerve agent use will fail. The molecular evidence will persist for a long time, typically months, sometimes for years. One way of collecting this evidence, apart from taking soil samples, is to harvest and extract contaminated vegetation, because as the

next section shows, it is excellent at keeping a readable record of nerve agent use, acting in many ways as a time capsule.

## Plant metabolism of nerve agents

Few reports on the interaction of CWAs with plants exist. Those that are accessible concern only a small selection of the most important nerve agents. The first reports, published in the 1970s, examined wheat as the test species.<sup>25-28</sup> Other reports published recently used white mustard as the test species (Figure 3).<sup>29,30</sup> The next subsections summarise key findings.

changes was not identified. Sarin and soman vapour was also absorbed by the leaves, by the pores effecting gaseous exchange (stomata), and degraded to the same products.<sup>27</sup> Thus, degradation pathways of the G-agents after leaf and root absorption were similar. The amounts of the methylphosphonic acid derivatives in the plant extracts were influenced by the vapour concentration of the G-agent, the period of exposure to the vapour, and the state of illumination of the plants. The study suggests that growing plants can absorb and possibly act as 'sinks' for atmospheric contamination by organophosphorus compounds. The phytotoxicity of G-agents was studied by examining the effects of the nerve agents and their



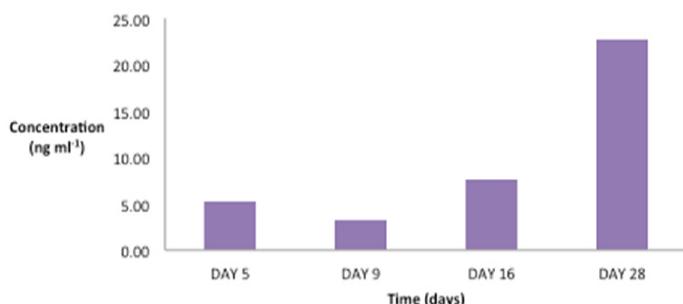
**Figure 3. Cover art of the recent papers on white mustard plants as nerve agent detectors published in the peer-reviewed journals Analytical Methods (The Royal Society of Chemistry, 2013)<sup>29</sup> and Proceedings of the Royal Society A (The Royal Society, 2014)<sup>30</sup> (reproduced with permission from both societies). The images show white mustard grown in soil contaminated with VX, depicted in bubbles to symbolise its absorption and breakdown by the plant.**

## (a) Wheat

Studies of winter wheat (*Triticum aestivum*) grown in hydroponic culture showed that G-agents added to the culture medium were absorbed by the roots and rapidly hydrolysed in the plant; in the case of sarin to iPMPA, and for the other nerve agents (e.g. soman) to the equivalent acid (e.g. PMPA) and MPA.<sup>25,26</sup> It was unclear why iPMPA was not converted to MPA by the plant, but PMPA was converted; the metabolic machinery effecting these

breakdown products on wheat seed germination and growth of the seedlings (14 to 18 days old) in hydroponic culture.<sup>28</sup> Sarin and soman were phytotoxic and this was a property of the nerve agents and not their degradation products. The phytotoxicity was influenced by the nature of the O-alkyl group of the nerve agent: sarin was less toxic than soman.

In the studies on wheat, the analysis by GC-MS of the nerve agents and their acidic breakdown products was performed after derivatisation of the latter with diazomethane. It was



**Figure 4.** Concentration of iPMPA in white mustard grown from seed in loam contaminated with 1 ml of 250 µg ml⁻¹ of aqueous iPMPA at 4 harvest time points.<sup>29</sup> The results for each time point represent an average of analyses of four plants and show that they absorb this sarin hydrolysis product over a period of weeks, to a maximum concentration measured at day 28.

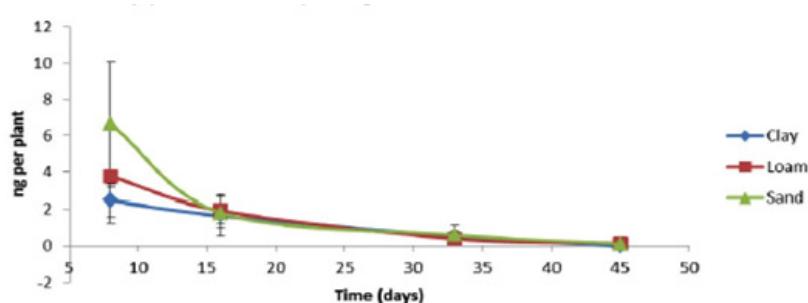
suggested that phytotoxicity might arise from inhibition of one or more enzymes in the plant. The approximate 30-year gap between the four studies described and the ones presented in the next subsection has witnessed huge advances in MS instruments; they are now more robust and sensitive, and can detect chemicals at much lower concentrations.

### (b) White mustard

Recent studies in the authors' laboratory with nerve agents and degradation products under conditions imitating their ground deposition were performed on white mustard (*Sinapis alba*).<sup>29,30</sup> This species was selected as it grows wild globally and in cultivation, reaching dimensions of 60 cm × 30 cm in sand, loam and heavy soils of acidic, basic and neutral pH. It is cultured for its edible leaves and seeds, and as a green manure due to its rapid growth and coverage. It has some advantages as a universal nerve agent detector: it has a wide geographical range, grows in all soil types, out-competes many weed species, self-seeds and spreads, and tolerates different climates. For these reasons, and because no previous studies had suggested a detection application for white mustard, we settled on this species to perform a series of experiments with the sarin degradation product iPMPA, and VX and its hydrolysis products.

The experiments involved addition of the white mustard seeds to the soil under investigation in cells in a compartmented plastic tray. The seeds were covered with the soil to the level of the top of the cells and contaminated with 1 ml of a 250 mg ml⁻¹ aqueous solution of test compound (nerve agent or breakdown product). The trays were watered with 10 ml of local borehole water at 24-hour intervals and placed under a lighting system that provided light (38,400 lumens) for 10 hours a day. The seeds germinated and grew into seedlings. These were harvested at set times, ground using a pestle and mortar, extracted with ethanol, and the resulting green solutions – containing photosynthetic pigments (e.g. chlorophyll) – filtered. These solutions, now free of proteins and other macromolecules, were analysed by LC-MS, or GC-MS after derivatisation (*tert*-butyldimethylsilylation).

Sarin upon contact with moisture hydrolyses rapidly to iPMPA. Spiking soil with small volumes of liquid sarin is not easy because of its high volatility and the difficulty of dispensing such a hazardous substance accurately by syringe. Overcoming this problem would not be satisfactory for the envisaged test as sarin vapour can penetrate foliage (noted for wheat) in addition to the liquid penetrating the roots. Uncertainty over accuracy of dispensing – the ratio of the amount evaporating from the soil (available for foliage uptake) to the amount hydrolysing in the soil (available for



**Figure 5.** Amount of VX detected in white mustard plants grown from seed in clay, loam and sand contaminated with 1 ml of 250 µg ml⁻¹ of aqueous VX (determined by LC-MS of ethanol extracts of pulverised plants). Data points are averages from analysis of 10 plants and the error bars indicate the data standard deviation.<sup>30</sup>

root uptake) – if sarin was added to the soil, would be high, and complicate making any conclusions of uptake by the roots alone. To minimise the variables, we mimicked sarin deposition by spiking the seeds with 1 ml of a 250 µg ml<sup>-1</sup> aqueous solution of iPMPA. This concentration was not visibly toxic to the seed and the seedlings grew similarly to untreated ones grown in the same fume cupboard.

Degradation products of sarin bind tightly to soils with a high organic content, and iPMPA soil spiked at the same concentration as that used as the seed dressing, followed by attempts to extract the soil with ethanol – or basification, extraction with water, and derivatisation – did not result in any recovery of iPMPA. However, by ethanol extraction of the plants, iPMPA was detected out to day 28 (Figure 4), potentially providing evidence of sarin use unobtainable from analysis of the soil alone.

White mustard seeds were grown in clay, loam or sandy soil spiked with VX, EMPA and MPA and the resulting plants were harvested after 8, 16, 33 and 45 days. The different soils moderated the initial uptake of VX, but not the longer term uptake, however, the duration the VX was detectable – to sub 1 ng of VX per plant – was the same (Figure 5). This showed that regardless of the soil type, evidence for the prior presence of VX in soil could be extracted from the plants at least 45 days after application. The plants metabolised the VX to EMPA and MPA, and the MPA found in the plants increased when they were grown in VX-spiked clay. When the seeds were grown in EMPA-spiked loam, no EMPA was detected in the plants. The MPA profile in plants grown in MPA-spiked loam matched the MPA profile in plants grown in VX-spiked loam. EMPA and MPA were detected for up to 45 days after sowing the seeds. These data suggest that the EMPA found in the plants grown in soil contaminated with VX originated from VX metabolism, demonstrating a possible application of the plants for bioremediation of contaminated land. This possibility is discussed later on.

The studies with wheat and white mustard indicate that these species are able to absorb G- and V-agents readily and convert them into harmless products, which can be detected by simple ethanol extraction and analysis by GC-MS (after derivatisation) and/or LC-MS. Although the nerve agent is expected to persist inside the plant for days (G-agents) or months (V-agents), the hydrolysis products are anticipated to remain for considerably longer, and therefore serve as markers of nerve agent use for a long

time afterwards. The next section examines whether further evidence might be obtained from plant biomarkers. These have not been considered before, but might constitute a source of additional information.

### (c) Plant biomarkers

Plant biomarkers could be useful for monitoring the environmental impact of demilitarisation activities. The metabolism of nerve agents in humans and plants appears to follow a similar course: the principal metabolites are the alkyl methylphosphonic acids (iPMPA for sarin, PMPA for soman, and EMPA for VX) and MPA. Despite this parallel, to our knowledge no investigation into alleged nerve agent use has examined vegetation for prospective molecular evidence. An attraction of using plants for this purpose is that control specimens outside the zone of attack, and therefore free of contamination, should be easy to find and collect. Shipment of plant material to the OPCW designated laboratories might be accompanied by deterioration of the vegetation, but this might be retarded by cold storage during the chain of custody. Alternatively plant extracts could be worked up in theatre, by fast and simple procedures, and then shipped for analysis elsewhere.

Analysis of crushed plant extracts is analogous to the analysis of urine from nerve agent casualties, which seeks to identify the same hydrolysis products. Can approaches for the identification of biomarkers in humans be applied to putative biomarkers from plants? In contrast to animal AChE, few data exist concerning the occurrence of cholinesterases in plants. An enzyme with AChE-like activity has been identified in wheat (*Triticum aestivum*),<sup>31</sup> white mustard (*Sinapis alba*)<sup>32,33</sup> and the tomato (*Lycopersicon esculentum*),<sup>34</sup> and an AChE characterised from maize (*Zea mays*).<sup>35,36</sup> More recently, cholinesterase activity was detected in 67 out of 118 plant species screened.<sup>37</sup> Not all parts showed activity in those that tested positive. All species of the families *Euphorbiaceae* and *Leguminosae* had activity. Most members of *Solanaceae* tested positive – leaves of the native gooseberry (*Physalis minima*) were especially rich in cholinesterase – and most of the *Asteraceae* tested negative. If the cholinesterases resemble human AChE structurally they should be inhibited similarly by nerve agents. In fact, diisopropyl phosphorofluoridate (DFP), a potent inhibitor of human AChE and a close structural analogue of sarin, inhibits plant cholinesterases.<sup>38</sup> Its use helped identify cholinesterase activity in about 70 species from 50 higher plant families and 3 families of fern.<sup>39</sup> The

pattern of inhibition of plant enzymes by DFP revealed that those with a sulfur atom, belonging to the amino acid cysteine, in their active sites, to which DFP (and G-agents) are quite unreactive,<sup>40</sup> were unaffected by DFP; only those thought to function presumably via a serine residue were inhibited. Radioactive P-32 labelled DFP was shown later to bind to a serine residue in an enzyme isolated from the French bean (*Phaseolus vulgaris*).<sup>41</sup> More plant AChEs might be discovered in time given the realisation that their natural substrate – acetylcholine – exists in many organisms without a nervous system, including plants, fungi and bacteria,<sup>42,43</sup> due to its postulated abundance during the early evolution of life.

There is also the possibility of using moss as a sample to detect nerve agents: bryophytes – land plants that include mosses, hornworts and liverworts – also contain cholinesterases. One study revealed that 30 species from 13 families of bryophyte had ChE activity.<sup>44</sup> The Indian moss *Anoectangium bicolor* had the highest activity. Mosses thrive in wet areas and might absorb water-soluble nerve agent degradation products (e.g. iMPMA and/or MPA).

The wide distribution of AChE throughout the plant kingdom invites treating extracts of plant tissue contaminated with nerve agents with fluoride, to regenerate the G-agent or produce the G-agent analogue (after V-agent exposure) for analysis by GC-MS. This has not been considered before but is possible at least theoretically. It offers a new line of analytical enquiry that might be rewarded with results of practical importance.

#### (d) Plant remediation of nerve agents

The idea of using plants to remediate land contaminated with nerve agents or their hydrolysis products is discussed elsewhere.<sup>30</sup> To summarise: one solution to remediate such land might be to cultivate *Sinapis alba* on it. The crop can be harvested and destroyed or returned to the soil to allow cultivation of a second crop. Each generation of plants will destroy a proportion of the nerve agent until it is fully depleted. This ‘green manure’ approach has benefits over traditional chemical remediation, such as bleach application or incineration. It is less costly, environmentally friendly, and does not require an energy source other than the sun.<sup>45</sup> It might also be possible to genetically engineer plants to hydrolyse nerve agents more efficiently and utilise their phosphorus content for normal growth. The metabolism of nerve agents by plants, as demonstrated for wheat and white mustard, is expected to be accompanied by detoxification by binding to cholinesterases within the plant (every molecule of a nerve agent inactivated this way is one less that could poison a human). It is of interest

that BuChE, which has potential as a therapeutic nerve agent scavenger in humans, has been produced by transgenic plants for medical countermeasure research.<sup>46,47</sup> The same plants would be anticipated to scavenge nerve agents systemically from the environment via their ‘implanted’ BuChE.

#### Conclusions

Approaches to confirmation of nerve agent use have been reviewed and scientific evidence gathered to demonstrate that plants may offer an extra sample option for investigations of alleged use. Plant analysis may be useful for environmental monitoring of pollution from abandoned chemical munitions or during demilitarisation. Fast-growing plants such as white mustard may also have value in bioremediation of contaminated sites. The discussion in this article, focusing on a topic exemplifying the convergence of chemistry and biology relevant to the implementation of the CWC, serves peace and security, and the goals of the OPCW<sup>48</sup> as the guardian of the global ban on chemical weapons. We hope it will inspire others to think about how analytical chemistry research can be harnessed to deter the future deployment of such weapons.

*Christopher Timperley is a Fellow of the Defence Science and Technology Laboratory (Dstl) at Porton Down in the UK, where he is the technical lead for chemistry. He was appointed to the OPCW Scientific Advisory Board in January 2013 and elected its Vice-Chair in June 2013.*

*Cerys Rees is the technical lead for analysis and attribution at Dstl Porton Down and has worked in this area for many years, including supporting the security of the 2012 Olympic Games in London.*

*James Riches is the technical lead for analytical chemistry at Dstl Porton Down. He has led Dstl’s designated laboratory to the OPCW since 2007, achieving seven consecutive A grades. He chairs the Validation Group for the OPCW, which evaluates spectroscopic data for the OPCW’s databases.*

*Matthew Gravett, Farrha Hopkins, Adam Self and Andrew Webb are analytical chemists at Dstl Porton Down and lead scientists within its designated laboratory. They were part of the team that performed the studies on the white mustard plants.*

*Matthew J. Baker, a former Research Fellow at Dstl Porton Down, conducted studies on the detection of chemical and biological warfare agents, before moving to the University of Central Lancashire (UCLan), to lead its Bioanalytical Sciences Research Group. He has recently been appointed as Senior Lecturer in Chemistry in the Department of Pure & Applied Chemistry, University of Strathclyde, Glasgow, Scotland.*

## References

1. June 2014, Convergence of Chemistry and Biology, Report of the Scientific Advisory Board's Temporary Working Group, OPCW, The Hague ([www.opcw.org](http://www.opcw.org)).
2. 1997 Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction (Chemical Weapons Convention), OPCW, The Hague ([www.opcw.org](http://www.opcw.org)).
3. Black RM, Read RW. 2007 Environmental and biomedical sample analysis in support of allegations of use of chemical warfare agents. *Toxin Revs.* **26**, 275-298.
4. Black RM. 2010 History and perspectives of bioanalytical methods for chemical warfare agent detection. *J. Chromatogr. B*. **878**, 1207-1215.
5. Black RM. 2008 An overview of biological markers of exposure to chemical warfare agents. *J. Anal. Toxicol.* **32**, 2-9.
6. Sellström A et al. 13 September 2013 UN Mission to Investigate Allegations of Chemical Weapons in the Syrian Arab Republic: Report on Allegations of the Use of Chemical Weapons in the Ghouta Area of Damascus on 21 August 2013.
7. Sellström A et al. 12 December 2013 United Nations Mission to Investigate Allegations of the Use of Chemical Weapons in the Syrian Arab Republic. Final Report.
8. Timperley CM. 2000 Highly-toxic fluorine compounds. Fluorine Chemistry at the Millennium: Fascinated by Fluorine (ed. RE Banks), Elsevier, Oxford UK, Chapter 29, pp. 499-537.
9. Black RM, Harrison JM. 1996 The chemistry of organophosphorus chemical warfare agents. *The Chemistry of Organophosphorus Compounds* (ed. FR Hartley), John Wiley & Sons, Chichester UK, Vol. 4, Chapter 10, pp. 781-840.
10. Schrader G. 1945 The development of new insecticides and chemical warfare agents. BIOS Final Report 714 Item No. 8 (reported by SA Mumford and EA Perren), London, UK.
11. Schrader G. 1951 Die entwicklung neuer insektizide auf grundlage organischer fluor- und phosphorverbindungen. Monographien zu "Angewandte Chemie" und "Chemie-Ingenieur-Technik" Nr. **62**, Verlag-Chemie GmbH, Weinheim, Germany.
12. Watkins TF. 1968 Chemical warfare. Chemical Warfare, Pyrotechnics and the Fireworks Industry (eds. TF Watkins, JC Cackett, RG Hall), Chapter 1, Pergamon Press Ltd., London UK, Part I, pp. 2-57.
13. Saunders BC. 1957 Some Aspects of the Chemistry and Toxic Action of Organic Compounds Containing Phosphorus and Fluorine, Cambridge University Press, Cambridge UK.
14. Riches J. Analysis of polar nerve agent hydrolysis products. *Chromatography Today*, August/September 2013, pp. 4-6.
15. Black RM, Muir B. 2003 Derivatisation reactions in the chromatographic analysis of chemical warfare agents and their degradation products. *J. Chromatogr. A*. **1000**, 253-281.
16. Timperley CM, Bird M, Holden I, Black RM. 2001 Organophosphorus chemistry. Part 1. The synthesis of alkyl methylphosphonic acids. *J. Chem. Soc., Perkin Trans. 1*, 26-30.
17. Barucki H, Black RM, Kinnear KI, Holden I, Read RW, Timperley CM. 2003 Solid-phase synthesis of some alkyl hydrogen methylphosphonates. *Phosphorus, Sulfur, and Silicon* **178**, 2279-2286.
18. Kingery AF, Allen HE. 1995 The environmental fate of organophosphorus nerve agents: a review. *Toxicol. Environ. Chem.* **47**, 155-184.
19. Munro NB, Talmage SS, Griffin GD, Waters LC, Watson AP, King JF, Hauschild V. 1999 The sources, fate, and toxicity of chemical warfare agent degradation products. *Environ. Health Perspect.* **107**, 933-974.

20. Bizzigotti GO, Castelly H, Hafez AM, Smith WH, Whitmire MT. 2009 Parameters for evaluation of the fate, transport, and environmental impacts of chemical agents in marine environments. *Chem. Rev.* **109**, 236-256.
21. Kim K, Tsay OG, Atwood DA, Churchill DG. 2011 Destruction and detection of chemical warfare agents. *Chem. Rev.* **111**, 5345-5403.
22. Schrader G. 1947 Synthetic Insecticides. BIOS Final Report No. 1808 Item No. 22, London UK, p. 20.
23. Hopkins FB, Gravett MR, Self AJ, Wang M, Hoe-Chee C, Lee Hoi Sim N, Jones JTA, Timperley CM, Riches JR. 2014 Chemical analysis of bleach and hydroxide-based solutions after decontamination of the chemical warfare agent O-ethyl S-2-diisopropylaminoethyl methylphosphonothiolate (VX). *Anal. Bioanal. Chem.* doi 10.1007/s00216-014-7674-2.
24. Gravett MR, Hopkins FB, Self AJ, Webb AJ, Timperley CM, Riches JR. 2014 Fate of the chemical warfare agent O-ethyl S-2-diisopropylaminoethyl methylphosphonothiolate (VX) on soil following accelerator-based fire and liquid decontamination. *Anal. Bioanal. Chem.* doi 10.1007/s00216-014-7963-9.
25. Hambrook JL, Howells DJ, Utley D. 1971 Degradation of phosphonates. Breakdown of soman (O-pinacolyl-methylphosphonofluoridate) in wheat plants. *Pestic. Sci.* **2**, 172-175.
26. Howells DJ, Hambrook JL, Utley D, Woodage J. 1973 Degradation of phosphonates II. The influence of the O-alkyl group on the breakdown of some O-alkyl methylphosphonofluoridates in wheat plants. *Pestic. Sci.* **4**, 239-245.
27. Howells DJ, Hambrook JL, Allenby EA. 1976 Uptake of some volatile alkyl methylphosphonofluoridates from the vapour phase by wheat plants. *Pestic. Sci.* **7**, 349-354.
28. Howells DJ, Hambrook JL. 1972 The phytotoxicity of some methylphosphonofluoridates. *Pestic. Sci.* **3**, 351-356.
29. Gravett MR, Hopkins FB, Main MJ, Self AJ, Timperley CM, Webb AJ, Baker MJ. 2013 Detection of the organophosphorus nerve agent VX and its hydrolysis products in white mustard plants grown in contaminated soil. *Anal. Methods* **5**, 50-53.
30. Gravett MR, Hopkins FB, Self AJ, Webb AJ, Timperley CM, Baker MJ. 2014 Evidence of VX nerve agent use from contaminated white mustard plants. *Proc. Roy. Soc. A* **470**, 20140076.
31. Molyneux DE, McKinlay RG. 1989 Observations on germination and acetylcholinesterase activity in wheat seeds. *Ann. Bot.* **63**, 81-86.
32. Tzagoloff A. 1963 Metabolism of sinapine in mustard plants. I. Degradation of sinapine into sinapic acid and choline. *Plant Physiol.* **38**, 202-206.
33. Tzagoloff A. 1963 Metabolism of sinapine in mustard plants. II. Purification and some properties of sinapine esterase. *Plant Physiol.* **38**, 207-213.
34. Wiśniewska J, Tretyn A. 2003 Acetylcholinesterase activity in *Lycopersicon esculentum* and its phytochrome mutants. *Plant Physiol. Biochem.* **41**, 711-717.
35. Sagane Y et al. 2005 Molecular characterization of maize acetylcholinesterase. A novel enzyme family in the plant kingdom. *Plant Physiol.* **138**, 1359-1371.
36. Yamamoto K, Sakamoto H, Momonoki YS. 2011 Maize acetylcholinesterase is a positive regulator of heat tolerance in plants. *J. Plant Physiol.* **168**, 1987-1992.
37. Gupta A, Gupta R. 1997 A survey of plants for presence of cholinesterase activity. *Phytochemistry* **46**, 827-831.
38. Jansen EF, Nutting MD, Balls AK. 1947 Apparent specific inhibition of plant acetyl esterase by diisopropyl fluorophosphates. *J. Biol. Chem.* **170**, 417-418.

39. Miura GA, Broomfield CA, Lawson MA, Worthley EG. 1982 Widespread occurrence of cholinesterase activity in plant leaves. *Physiol. Plant* **56**, 28-32.
40. Timperley CM, Saunders SA, Szpalek J, Waters MJ. 2003 Fluorinated phosphorus compounds. Part 8. The reactions of bis(fluoroalkyl) phosphorochloridates with sulfur nucleophiles. *J. Fluorine Chem.* **119**, 161-171.
41. Shaw DC, Wells JRE. 1972 Radiochemical determination of a unique sequence around the reactive serine residue of a diisopropyl phosphorofluoridate-sensitive plant carboxypeptidase and a yeast peptidase. *Biochem. J.* **128**, 229-235.
42. Kawashima K et al. 2007 Ubiquitous expression of acetylcholine and its biological functions in life forms without nervous systems. *Life Sci.* **80**, 2206-2209.
43. Horiuchi Y et al. 2003 Evolutional study on acetylcholine expression. *Life Sci.* **72**, 1745-1756.
44. Gupta A, Thakur SS, Uniyal PL, Gupta R. 2001 A survey of bryophytes for presence of cholinesterase activity. *Am. J. Bot.* **88**, 2133-2135.
45. Baker MJ, Gravett MR, Hopkins FB, Self AJ, Webb AJ, Timperley CM. Cutting the mustard: evidence of VX nerve agent use from contaminated white mustard plants. Oral presentation at the 17th International Chemical Weapons Demilitarisation Conference CWD 2014, sponsored by the British Defence Science and Technology Laboratory and British Ministry of Defence, 4-6 June 2014, London, UK.
46. Geyer BC et al. 2010 Transgenic plants as a source for the bioscavenging enzyme, human butyrylcholinesterase. *Plant Biotechnol. J.* **8**, 873-886.
47. Geyer BC et al. 2010 Plant-derived human butyrylcholinesterase, but not an organophosphorus-compound hydrolyzing variant thereof, protects rodents against nerve agents. *Proc. Natl. Acad. Sci. USA* **107**, 20251-20256.
48. Üzümcü A. 10 December 2013 Working Together for a World Free of Chemical Weapons, and Beyond. Nobel Peace Prize Lecture OPCW ([www.nobelprize.org](http://www.nobelprize.org)).



Inspectors testing a chemical agent monitor

# Science for the Comprehensive Nuclear-Test-Ban Treaty

By Martin B. Kalinowski

The monitoring system of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) is an example of how scientific collaboration and data sharing across borders is beneficial to global security. Engaging the scientific community to be part of the security network has proven to be vital to achieve the international norm of non-testing. The scientific community is gaining a tremendous return in an unprecedented data set and new technologies and analytical methodologies that opens up a vast range of civil and scientific applications.

The first test ban treaties (Partial Test Ban Treaty, PTBT, 1963; Threshold Test Ban Treaty, 1972) had no provisions for verification and relied on national technical means. National approaches for detecting foreign nuclear explosions date back to the very early times of nuclear weapons testing. Many radiation laboratories in the world have analysed atmospheric samples in combination with atmospheric transport simulations to retrieve information about nuclear tests. In 1976, the Group of Scientific Experts (GSE) was established at the Conference on Disarmament in Geneva in order to develop and demonstrate collaborative seismic monitoring capabilities. During the two decades of their work, the GSE and the radiation laboratories paved the way for the CTBT negotiations by demonstrating a crucial element of the verification with three successive technical tests (GSETT).

The work of scientists between the 1950s and 1993 removed the technical hurdles so that the Comprehensive Nuclear-Test-Ban Treaty (CTBT) could be successfully negotiated by the Conference on Disarmament in Geneva between 1993 and 1996. It was opened for signature on 24 September 1996. As of June 2014, the Treaty was signed by 183 States and ratified by 162, 36 of which belong to the group of 44 States for which ratification is required for the CTBT to enter into force. The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Organisation (CTBTO) was established to carry out the necessary preparations for the effective implementation of the CTBT. The organisation started its work in March 1997 in Vienna.

The CTBT is a crucial cornerstone of the universal norm

of nuclear non-proliferation and has for many years been considered by many as a top priority in moving towards a nuclear-weapons-free world. Due to the diligent work of scientists from various disciplines, the Treaty is technically ready for Entry into Force. The CTBTO put in place a credible and robust verification system that has impressively been demonstrated by the detection of all three announced nuclear explosions of the Democratic People's Republic of Korea (DPRK) in 2006, 2009 and 2013, as well as by the analysis of signatures from many other diverse events such as the great Tohoku earthquake of 11 March 2011, the subsequent tsunami and the nuclear power plant accidents in Fukushima.

In order to verify compliance with the nuclear test ban, the International Monitoring System (IMS) consisting of 337 monitoring facilities around the globe is being established in order to monitor the entire globe using four different sensor technologies. When complete, the seismic network will consist of 50 primary and 120 auxiliary seismological stations to monitor the solid earth, the hydroacoustic network will comprise 11 stations to monitor the oceans, and 60 infrasound and 80 radionuclide stations will monitor the atmosphere. In addition, 16 countries host dedicated radionuclide laboratories to provide high-quality sample analyses.

The IMS is now more than 85% complete. The International Data Centre (IDC) provides all State Signatories with full access to the data in near-real time and to related analysis products as they become available. The on-site inspection (OSI) capabilities are tested regularly and will be demonstrated during the next Integrated Field Exercise (IFE14), scheduled to take place in Jordan in the autumn of 2014.

Scientists continue to improve on the verification system to keep it up to date with the latest scientific and technical developments and even to create novel types of sensors and approaches that reach beyond those conceived during treaty negotiations. The data and products are more and more being used for civil and scientific applications like tsunami early warning and meteorite detection. This

increases the integration of the CTBTO in international cooperation with the science and technology communities and ensures its long-term sustainment and its continued advances in improving CTBT verification. The growing community of users brings additional expertise and research and development that further improve the efficiency and effectiveness of nuclear explosion monitoring.

The international scientific community is instrumental in achieving the goal of constant improvement of the verification regime. Scientists drive the relevant research and technical innovations that may shape the future of nuclear explosion monitoring. According to Article IV, 11 of the CTBT, “*Each State Party undertakes to cooperate with the Organization and with other States Parties in the improvement of the verification regime, and in the examination of the verification potential of additional monitoring technologies such as electromagnetic pulse monitoring or satellite monitoring, with a view to developing, when appropriate, specific measures to enhance the efficient and cost-effective verification of this Treaty.*”

The CTBTO undertakes special endeavours to ensure that the complete monitoring system from sensor technology to analysis algorithms is state-of-the-art. Many technical workshops are organised every year. An important opportunity for interaction with the broader scientific community is the science and technology conference series at the Hofburg imperial palace in Vienna. It started in 2006 with a scientific symposium on “CTBT: Synergies with Science 1996-2006 and beyond” (CTBTO, 2006), continued in 2009 with the International Scientific Studies (ISS) Conference (CTBTO, 2009), followed by the CTBT Science and Technology (SnT) Conference 2011 (CTBTO, 2011) and the CTBT SnT Conference 2013 (CTBTO, 2013).

Many regular meetings of international scientific associations are used to host special sessions dedicated to encouraging a dialogue within the scientific community on research relevant to nuclear explosion monitoring. The progress is documented, for example, in two recent topical volumes of Pure and Applied Geophysics on “Recent Advances in Nuclear Explosion Monitoring” (PAGEOPH, 2010 and 2014). These volumes are follow-up to research published in a series of topical volumes in the years 2001-2002 (PAGEOPH, 2001a,b,c,d,e; PAGEOPH, 2002a,b).

In all sensor technologies and relevant scientific disciplines,

significant advances in nuclear explosion monitoring have been achieved. This progress in the development and testing of new methods improves the capabilities in detection, location and characterisation of CTBT relevant events. In particular the latter poses a challenge for smaller events, where natural or manmade, but CTBT irrelevant, sources can generate false positive events. The efficient detection and characterisation of any event of interest has advanced well beyond the requirements used to design the IMS network during the CTBT negotiations.

*Disclaimer: The views expressed in this publication are those of the author and do not necessarily reflect the views of the CTBTO.*



Martin B. Kalinowski is Chief, Capacity Building and Training Section in the International Data Centre (IDC) Division of the Provisional Technical Secretariat of the CTBTO Preparatory Commission. Martin Kalinowski holds a PhD in nuclear physics. From 2006 to 2012, he was Professor for Science and Peace Research at the University of Hamburg, Germany. In 1998, he joined the IDC the first time.

## References

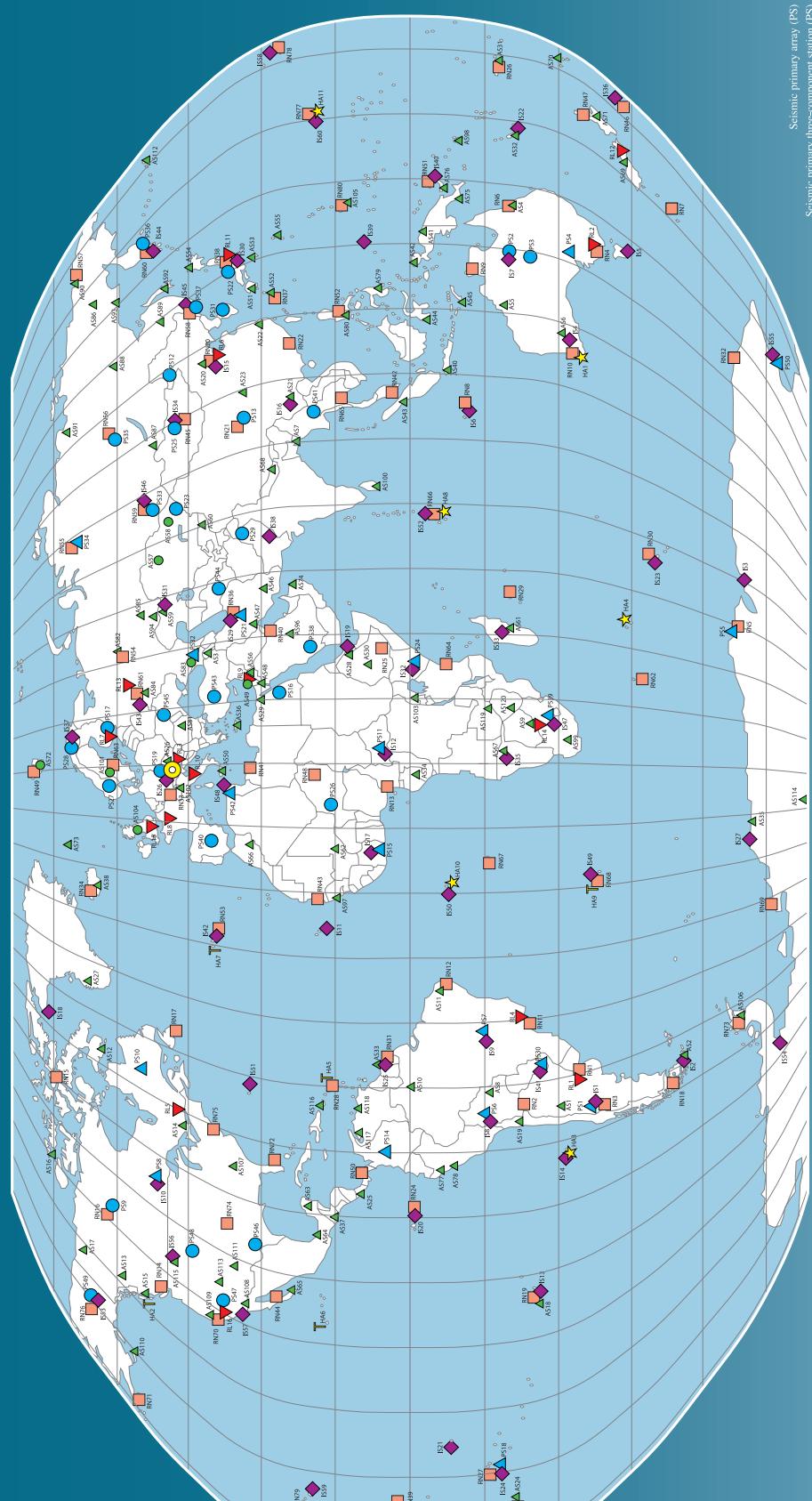
CTBTO (2006), CTBT: Synergies with science 1996-2006 and beyond symposium website on [www.ctbto.org/specials/ctbt-synergies-with-science1996-2006-and-beyond/](http://www.ctbto.org/specials/ctbt-synergies-with-science1996-2006-and-beyond/)

CTBTO (2009), International Scientific Studies (ISS) Conference conference website on [www.ctbto.org/specials/the-international-scientific-studies-project-iss/](http://www.ctbto.org/specials/the-international-scientific-studies-project-iss/)

CTBTO (2011), CTBT Science and Technology Conference 2011 conference website on <http://www.ctbto.org/?id=2538>

CTBTO (2013), CTBT Science and Technology Conference 2013 conference website on [www.ctbto.org/specials/snt2013/](http://www.ctbto.org/specials/snt2013/)

## INTERNATIONAL MONITORING SYSTEM



The boundaries and presentation of material on this map do not imply the expression of any opinion on the part of the Provisional Technical Secretariat of the Preparatory Commission or the Comprehensive Nuclear-Test-Ban Treaty Organization on the legal status of any country's territory, city or town or its authorities, or concerning the delimitation of its frontiers or boundaries.

Chart L, revised July 2003

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) of 1996 bans nuclear explosions in all environments. Explosions in the atmosphere, under water and in outer space were banned in 1963. CTBT prohibits them underground as well. This network of 321 monitoring stations is being established to record data necessary to verify compliance with the Treaty. Supported by 16 radionuclide laboratories, this network of 321 monitoring stations will be capable of registering shock waves emanating from a nuclear explosion underground, in the air, as well as detecting radioactive debris released into the atmosphere. The location of the stations has been carefully chosen for optimal and cost-effective global coverage.

The monitoring stations will transmit via satellite, the data to the International Data Centre (IDC) within CTBTO PrepCom in Vienna, where the data will be used to detect, locate and characterize events. These data and IDC products will be made available to the States Signatories for final analysis.

Overall is a listing of the 337 facilities of the international monitoring system and brief descriptions of their characteristics and capabilities.

- Seismic primary array (PS)
- Seismic auxiliary array (AS)
- Hydroacoustic (T-phase) station (HA)
- Infrasound station (IS)
- Radiouincide station (RN)
- Radionuclide laboratory (RL)
- International Data Centre, CTBTO PrepCom, Vienna

## OPCW Today

PAGEOPH (2001a), Monitoring the Comprehensive Nuclear-Test-Ban Treaty: Source Location (Ringdal, F. and Kennett, B.L.N. eds.), *Pure Applied Geophys*, **158**, No.1/2

PAGEOPH (2001b), Monitoring the Comprehensive Nuclear-Test-Ban Treaty: Hydroacoustics (deGroot Hedlin, C. and Orcutt, J. eds.), *Pure Applied Geophys*, **158**, No.3

PAGEOPH (2001c), Monitoring the Comprehensive Nuclear-Test-Ban Treaty: Regional Wave Propagation and Crustal Structure, (Patton, H.J. and Mitchell, B.J. eds.), *Pure Applied Geophys*, **158**, No.7

PAGEOPH (2001d), Monitoring the Comprehensive Nuclear-Test-Ban Treaty: Surface Waves (Levshin, A.L. and M.H. Ritzwoller eds.), *Pure Applied Geophys*, **158**, No.8

PAGEOPH (2001e), Monitoring the Comprehensive Nuclear-Test-Ban Treaty: Source Processes and Explosion Yield Estimation, (Ekström, G., Denny, M.

and Murphy, J.R., eds.), *Pure Applied Geophys*, **158**, No.11

PAGEOPH (2002a), Monitoring the Comprehensive Nuclear-Test-Ban Treaty: Seismic Event Discrimination and Identification, (Walter, W.R. and Hartse, H.E., eds.), *Pure Applied Geophys*, **159**, No.4

PAGEOPH (2002b), Monitoring the Comprehensive Nuclear-Test-Ban Treaty: Data Processing and Infrasound, (Der, Z.A., Shumway, R.H. and Herrin, E.T., eds.), *Pure Applied Geophys*, **159**, No.5

PAGEOPH (2010), Recent Advances in Nuclear Explosion Monitoring, (Becker, A., Schurr, B., Kalinowski, M.B., Koch, K., And Brown, D., eds.) *Pure Applied Geophys*, **167**, No. 4-5.

PAGEOPH (2014), Recent Advances in Nuclear Explosion Monitoring, Volume II (Kalinowski, M.B., Becker, A., eds.) *Pure Applied Geophys*, **171**, No. 3-5.

## Connect with OPCW Social Media



[www.facebook.com/opcwonline](http://www.facebook.com/opcwonline)



[www.twitter.com/opcw](http://www.twitter.com/opcw)



[www.youtube.com/opcwonline](http://www.youtube.com/opcwonline)



[www.flickr.com/opcw](http://www.flickr.com/opcw)



[www.gplus.to/opcw](http://www.gplus.to/opcw)

# Scientific Research At the Core of the OPCW International Cooperation Programme

The Technical Secretariat provides assistance to the science and technology community in developing countries and countries with economies in transition which are States Parties to the Chemical Weapons Convention (CWC). The OPCW Programme for Support of Research Projects, together with the programmes for internships and conference support, is among the tools within the chemical knowledge promotion and exchange area of activities, and is resourced through the International Cooperation and Assistance (ICA) Programme of the OPCW.

Scientific research, and new scientific knowledge generated as a result of such research, lays the basis for the development of new technologies and contributes to the sustainable development of countries. In the case of chemical industry, R&D is the starting point for developing new commercial products and processes which are greener, safer and more profitable than traditional ones. Novel methods of analytical chemistry are being introduced in many areas, ranging from environmental monitoring to food analyses and customs control procedures.

Chemistry as a scientific discipline has always been central to the Convention. Now, as the destruction of declared stockpiles of chemical weapons is coming to a conclusion, the work of the OPCW in promoting research, as well as economic and technological development in the field of chemistry, becomes even more important. By supporting scientific research, the OPCW seeks to balance the numerous obligations that the Convention imposes on its Member States and their chemical industries. The OPCW Programme for Support of Research Projects prioritises selected thematic fields which are directly relevant to the scope of implementation activities of the CWC, e.g. verification techniques or destruction technologies. Furthermore, the proposals which deal with safe and

sustainable applications of chemistry (chemistry of natural substances, green chemistry, environmental clean-up, pollution monitoring, water quality, etc.) and that enable the development goals of States Parties are also supported.

It must be noted that the OPCW is not a funding agency; it has very limited resources. Consequently, only minor laboratory running costs are covered, such as consumables, disposables and repairs, with the total budget per project normally limited to a maximum of €25,000 for a period up to three years. The support is offered to research groups who already have a good background in the proposed field of research and where adequate infrastructure and resources are already in place. The eligible proposals are subject to the approval by the National Authority or Permanent Representation of States Parties, and are then subjected to a careful evaluation by the Technical Secretariat review committee which meets twice a year and is composed of independent experts and Technical Secretariat staff.



**Chemistry as a scientific discipline has always been central to the Convention**

The number of projects directly supported each year by the OPCW varies between five and ten. A larger number, up to 30, are annually funded in a joint project with the International Foundation for Science (IFS), based in Stockholm. Cooperation with other funding programmes is essential as it increases the number of beneficiaries and creates better outreach and programme visibility. The OPCW is publishing a compilation of project reports, and a joint OPCW-IFS research prize ceremony is currently being discussed. The Secretariat also actively advertises the programme at various occasions, including meetings with National Authorities, workshops and training courses, however a great deal of outreach remains to be done in order to increase the application rate for this and other International Cooperation programmes. This is currently being achieved through institutional networking, social media and cooperation with professional societies.

# OPCW Today

Examples of projects that have received OPCW funding, include the development of novel biosensors for detection of toxicants,<sup>1,2</sup> applications of modern analytical chemistry methodologies,<sup>3</sup> studies of new materials and alternatives to toxic chemicals.<sup>4</sup> Common thematic areas in the research proposals we receive are sustainable chemistry<sup>5</sup> and drug development; both areas being highly relevant to developing economies. In the area of drug development, funding has been provided for studies on inflammatory and parasitic diseases,<sup>6</sup> diabetes<sup>7</sup> and cancer.<sup>8</sup>

The research projects programme is seen as an integrated part of the family of OPCW capacity building programmes. Recipients of research grants can become beneficiaries of other programmes such as conference support, analytical skills development courses or equipment exchange programmes. In addition, some researchers who have been sponsored by the OPCW have continued to support the work of the Organisation in various ways.

A number of improvements for the research projects programme have been discussed at recent meetings of the review committee, at workshops and internally. Consideration is being given to improving the quality of the funded projects by either narrowing the eligible thematic fields of research (e.g. with more focus on toxic chemicals and verification techniques) or, instead, widening the thematic focus and as a result enabling the selection to be based on the scientific quality rather than thematic relevance. However, the starting challenge for both scenarios is to increase the awareness of the programme within the scientific community and motivating the PRs and NAs for their active participation at both approval and dissemination levels. Other points of prospective improvements would be a higher participation of young scientists, facilitation of application procedures, better technical and financial monitoring, and introduction of activities to recognise achievements and to disseminate results of the OPCW research projects globally.

More information on the OPCW Programme for Support of Research Projects can be found on our website at: [www.opcw.org/our-work/international-cooperation/capacity-building-programmes/research-projects-support-programme/](http://www.opcw.org/our-work/international-cooperation/capacity-building-programmes/research-projects-support-programme/)

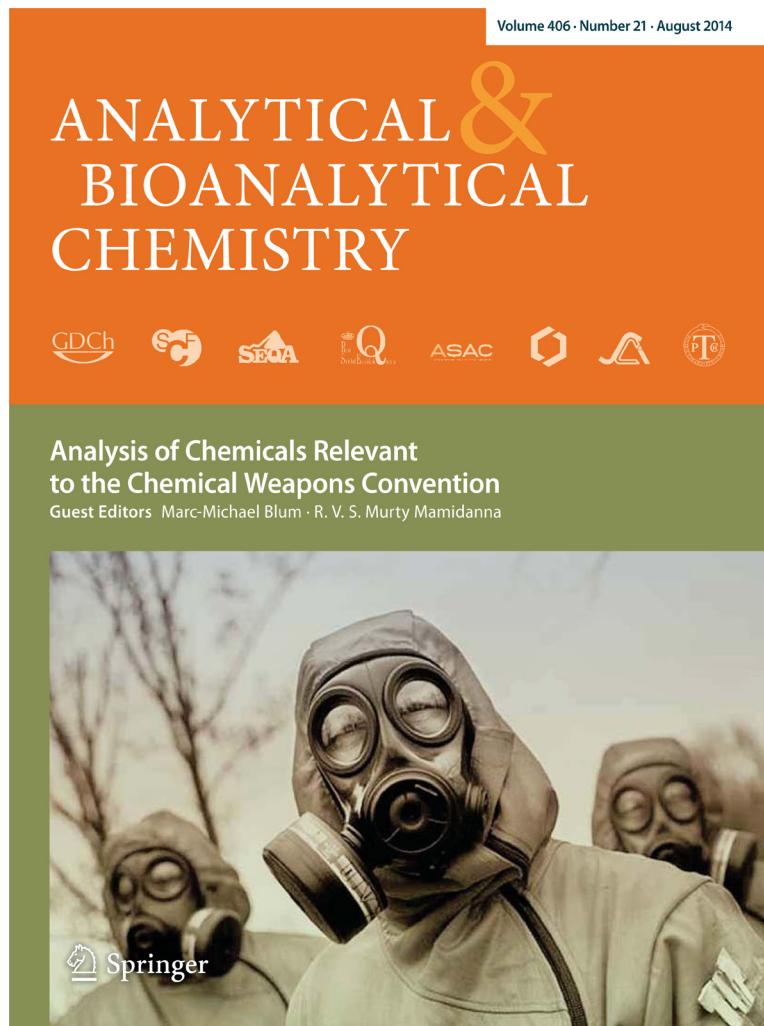
More information on other OPCW capacity building

programmes can be found on our website at: [www.opcw.org/our-work/international-cooperation/capacity-building-programmes/](http://www.opcw.org/our-work/international-cooperation/capacity-building-programmes/)

## References

1. Onani, M. O., Okil, J. O., Dejene, F. B. (2014). Solution–combustion synthesis and photoluminescence properties of YBO<sub>3</sub>:Tb<sup>3+</sup> phosphor powders. *Physica B: Condensed Matter*, **439**, 133-136.
2. Fuku, X., Iftikar, F., Hess, E., Iwuoha, E., Baker, P. (2012). Cytochrome c biosensor for determination of trace levels of cyanide and arsenic compounds. *Analytica chimica acta*, **730**, 49-59.
3. Musharraf, S. G., Ali, A., Choudhary, M. I. (2014). Probing of Metabolites in Finely Powdered Plant Material by Direct Laser Desorption Ionization Mass Spectrometry. *Journal of the American Society for Mass Spectrometry*, **25**(4), 530-537.
4. Wang, D. Y., Das, A., Leuteritz, A., Mahaling, R. N., Jehnichen, D., Wagenknecht, U., & Heinrich, G. (2012). Structural characteristics and flammability of fire retarding EPDM/layered double hydroxide (LDH) nanocomposites. *RSC Advances*, **2**(9), 3927-3933.
5. Perna, V., Castelló, E., Wenzel, J., Zampol, C., Fontes Lima, D. M., Borzacconi, L., Etchebehere, C. (2013). Hydrogen production in an upflow anaerobic packed bed reactor used to treat cheese whey. *International Journal of Hydrogen Energy*, **38**(1), 54-62.
6. Ibrahim, M. A., Mohammed, A., Isah, M. B., & Aliyu, A. B. (2014). Anti-trypanosomal activity of African medicinal plants: A review update. *Journal of ethnopharmacology*, **154**(1), 26-54.
7. Khan, K. M., Khan, M., Ambreen, N., Taha, M., Rahim, F., Rasheed, S., Choudhary, M. I. (2013). Oxindole derivatives: Synthesis and antiglycation activity. *Medicinal Chemistry*, **9**(5), 681-688.
8. Shaheen, F., Rizvi, T. S., Musharraf, S. G., Ganesan, A., Xiao, K., Townsend, J. B., Choudhary, M. I. (2012). Solid-phase total synthesis of cherimolacyclopeptide E and discovery of more potent analogues by alanine screening. *Journal of natural products*, **75**(11), 1882-1887.

# A topical collection on chemical weapon analysis



Two senior analytical chemists from the OPCW Laboratory initiated and edited a special issue for the peer-review journal *Analytical & Bioanalytical Chemistry* titled “Analysis of Chemicals Relevant to the Chemical Weapons Convention”.

Published as Issue 21 - August 2014, the collection of articles is freely available through 15 January 2015. The issue and its content can be accessed via the following weblink:

<http://link.springer.com/journal/216/406/21>.



Working together for a world free  
of chemical weapons



[www.opcw.org](http://www.opcw.org)