

Multiple Uses of Chemicals

IUPAC and OPCW Working Toward Responsible Science

by Peter Mahaffy, Joseph Zondervan,
Alastair Hay, Daniel Feakes, and
Jonathan Forman

Imagine being a chemist in the summer of 1941, four years prior to the end of the Second World War. The pressure to use the powerful knowledge of chemistry in service of national and political interests is enormous. The end result? At the Auschwitz Nazi extermination camp, Zyklon B, an infamous weapon of mass destruction, is first used. Over the next four years it claims responsibility for the lives of several million people in the gas chambers of Auschwitz and other death camps. When mixed with water, Zyklon B releases hydrogen cyanide, which fatally interferes with the respiratory processes of those inhaling it. Hydrogen cyanide is a simple, triatomic molecule whose power for destruction is now burned into our global consciousness as a symbol of how badly things can go wrong when the tools of chemistry are misused. Prior to the Second World War, hydrogen cyanide had been used as a delousing agent and insecticide, and this toxicity inspired its use in designing a new way to kill people.

However, this story of a molecule does not end in the gas chambers, and it is more than a horror story of the misuse of a chemical substance. More than 70 years later, hydrogen cyanide is produced annually in million-tonne quantities. Most of that HCN is used in a variety of important and beneficial industrial processes, such as manufacturing paints, producing chelating agents, and synthesizing adiponitrile, a precursor to nylon. Hydrogen cyanide is a good example of a substance that can both improve the quality of life and be employed for destruction of life. Such is the nature of *multi-use chemicals—substances which can be used for a variety of applications, ranging from beneficial to harmful, and at other points along the spectrum between these extremes.*

Fast-forward to being a chemist or chemist-in-training 72 years after the use of Zyklon B. The pressure to misuse the power of multi-use chemicals is demonstrated again in the early morning hours of 21 August 2013, when the world watches in horror as sarin, produced from a variety of beneficial substances including isopropanol (rubbing alcohol) and a chemical compound used as a flame retardant, is unleashed on a civilian population in the East Ghouta suburbs of Damascus, Syria. A few months later, after mobilizing a global response to the Syria attack, the Organization for the Prohibition of Chemical Weapons (OPCW) is awarded the Nobel Peace Prize for its “extensive efforts to eliminate chemical weapons,” many of which are created from multi-use precursors. As the implementing body for the Chemical Weapons Convention, the OPCW seeks to monitor and prevent the production of chemical weapons, as well as destroy existing chemical weapon stockpiles in any of its states parties. In his Nobel Peace Prize Lecture, OPCW Director-General Ahmet Üzümcü declares that it is the task of the OPCW “to consign chemical weapons to history, forever.”

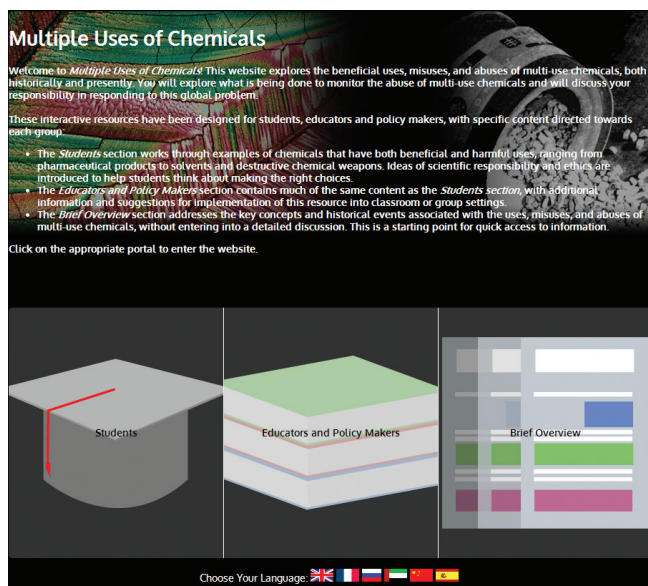
Educate and Raise Awareness

The desire to ensure that stories, such as those described here, about responsible choices regarding the multiple uses of chemicals are told to students, the public, and policy makers has provided the motivation for IUPAC and the OPCW to work together. Various initiatives have been supported for over a decade to give emphasis to education and awareness about the responsible practice of science. As emphasized in the Director-General's Nobel Peace Prize Lecture, organizations (such as the OPCW and IUPAC) need to



Making responsible choices can be a dilemma ... let's explore what it means to practice chemistry responsibly.

Multiple Uses of Chemicals



Homepage of www.iupac.org/multiple-uses-of-chemicals —the website designed to present educational material regarding the uses and misuses of multi-use chemicals, and to teach chemists and teachers about the importance of regulatory agencies such as the Chemical Weapons Convention and the creation of codes of conduct.

think “about how [they] can employ new communication tools to raise awareness of the need to practice responsible science, to instill the highest ethical standards in our future scientists and researchers.”

Chemical Weapons: The Human Toll

A stark reminder of the importance of communicating responsibility with respect to multi-use chemicals comes from grasping the short- and long-term human toll of the use of chemical weapons in Syria in 2013 and Iran in the late 1980s. 1000 people (mainly civilians) were killed in the August 2013 sarin attack near Damascus. Still unknown are the number injured in this attack and the extent of continuing health problems. So far no investigations have addressed this issue. During the Iraq/Iran war chemical weapons were used extensively by Iraq against Iranian soldiers and civilians, and in 1988 by Iraq against its own Kurdish community. At least 7000 Kurds died from chemical weapons in these attacks. Most were civilians, including many women and children. Well over 7000 were injured and millions of Kurds fled across borders into neighbouring Iraq, Turkey and Syria out of fear of the effects of these agents. The number of people who still bear the scars of these attacks in Kurdish areas is also unknown. At least two chemical weapons,

The OPCW strives to achieve its goal “to consign chemical weapons to history, forever,” through scientific work related to verification, international cooperation, and most recently, through education and outreach. Education is increasingly recognized as one of the first lines of defense to prevent the abuse of chemical substances, by equipping the public to respond to these issues. IUPAC is also concerned with ensuring that chemistry is practiced in a safe and beneficial way. IUPAC’s vision is “to advance the worldwide aspects of the chemical sciences and to contribute to the application of chemistry in the service of humankind.” To help ensure that chemistry acts “in the service of humankind,” IUPAC works through its Committee on Chemistry Education to provide free educational resources to raise awareness about the responsible use of chemistry in modern society.

One concrete step toward raising awareness of the need to practice responsible science has been taken through a joint IUPAC-OPCW project (project 2005-029-1-050 and 2013-020-1-050) to create a set of interactive electronic materials, *Multiple Uses of Chemicals*. This website (www.iupac.org/multiple-uses-of-chemicals) introduces students, educators, and policymakers to the topic of multi-use chemicals, and discusses how they can be used for beneficial purposes and misused to create illegal drugs or even chemical weapons. The website also includes

mustard gas and a nerve agent, possibly sarin, were used in the attacks. A nerve agent caused most of the fatalities. Iran still treats 30000 people, mainly former soldiers, for mustard gas related injuries. However, those being treated are the ones who were able to prove injury from mustard gas because of their army affiliations. Many others were not able to establish a causal link between mustard gas and their injuries, and have had to manage as best they can.

One of the major complications in making chemical weapons is the safety of the workforce involved in their manufacture, because of the potency of these substances. Creating these chemical weapons is within the reach of most competent chemists and the precursors are well known. It is, of course, illegal to do this and most countries have severe penalties for those who may be tempted. *Multiple Uses of Chemicals* was created, in part, to open the eyes of those who could be tempted, and to show them the destructive results that could result from their choices and actions.

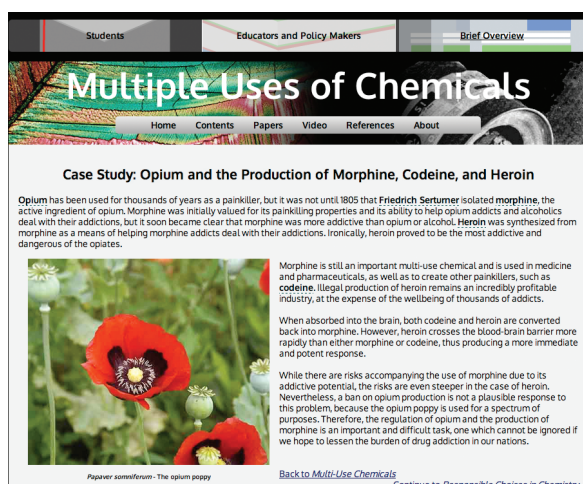
IUPAC and OPCW Working Toward Responsible Science

video footage that demonstrates how this complex set of topics can be communicated in engaging and informative ways with educators and chemists. The joint project was led by Peter Mahaffy (Canada), and Alastair Hay (UK), and included other members of the OPCW Temporary Working Group on Education and Outreach: Jan Apotheker (Netherlands), Djafer Benachour (Algeria), Jo Husbands (USA), Robert Matthews (Australia), Ting-Kueh Soon (Malaysia), and Alejandra Suarez (Argentina). An interdisciplinary team of undergraduate students and faculty at the King's Centre for Visualization in Science (www.kcvs.ca), under the direction of Peter Mahaffy and Brian Martin, developed the educational materials, in close consultation with scientists and educational specialists from both IUPAC and the OPCW. Additional funding for the project was provided by the European Union through the OPCW.

A Versatile Online Resource

Following best practices in the design of electronic learning materials, the *Multiple Uses of Chemicals* website resource was made with interactivity in mind, implementing a variety of case studies and role-playing scenarios to communicate information effectively. To engage a wide range of audiences while delivering content appropriate to each type of user, the resource starts with three separate portals: *Brief Overview*, *Students*, and *Educators and Policymakers*.

The *Brief Overview* displays the major features of the resource, and is highly condensed for easy navigation through the site. The *Students* portal targets secondary and post-secondary chemistry classes, and can be used to stimulate discussions of scientific responsibility and integrity in the context of applications of



various concepts in general and organic chemistry, or to support courses in ethics. Interactive resources for students include role-playing scenarios, case studies, and a variety of personal and discussion questions. The *Educators and Policymakers* section contains tips for implementing the resource into presentations or classroom discussions, as well as a list of learning outcomes for each topic, supplementary resources such as worksheets for students, and links to other websites that may be useful in preparing presentations or lectures.

The website is divided into four major sections: *Multi-Use Chemicals*, *Responsible Choices in Chemistry*, *Convergence of Chemistry and Biology*, and *Codes of Conduct*. The majority of the content is in the first two sections, where users are introduced to the concept of multi-use chemicals and the problems associated with their regulation and distribution.

The *Multi-Use Chemicals* section explores the concept of multi-use chemicals, starting with three case

Complementary OPCW Education and Outreach Resources

In addition to the Joint IUPAC/OPCW Multiple Uses of Chemicals resources, the OPCW has published other resources, exploring the history and science behind chemical warfare agents:

- **Fires** is a documentary film series exploring the historical context for chemical weapon use, abuse, regulation, and prevention, while also investigating the motivations and inspirations for both the producers and monitors of chemical weapons. Find it at: www.thefiresproject.com

- **Chemistry in Conflict** is an educational module for high school students, designed to introduce students to chemical weapons, the Chemical Weapons Convention, and ethics in science. It provides both a rich context for educating in chemistry, and historical background to the production and regulation of chemical weapons. A diverse set of activities, case studies and exercises facilitate instructor implementation. Feedback is currently being incorporated into the resource, after which it will be made freely and publicly available. (See OPCW Today, Dec 2013 (same as ref.3), pp. 25-26.)



Multiple Uses of Chemicals

studies on the production of illegal drugs. It is unlikely that most university students have given much thought to the production of chemical weapons. However, they may have been tempted by the easy money which can be obtained from synthesizing illegal drugs from readily available precursors, especially when their syntheses are so simple. Workshops have shown that introducing multi-use chemicals through examples of the synthesis of illegal drugs is relevant to most audiences, and effectively stimulates discussion of scientific ethics and responsibility. Three case studies are presented: the production of heroin from extracts of the opium poppy; the preparation of methamphetamine from ephedrine and other precursors; and the synthesis of methylenedioxymethylamphetamine (ecstasy) from safrole. Each of these case studies displays not only the availability but also the industrial importance of the precursors to these drugs, showing that the regulation of these drugs is not simply a matter of banning their precursors, as this would prevent the production of a variety of important industrial and consumer products. Rather, the prevention of illegal drug production requires strict monitoring of these precursors, so as to not restrict the beneficial applications of these substances. This section then explores the historical use of chemical warfare agents through a slideshow of photographs showcasing their first modern use in the First World War to their recent use in Syria. This helps to emphasize both the historical devastation and modern relevance of the production of chemical warfare agents. Following this are four case studies on the production of chemical weapons, three on the production of Zyklon B, mustard gas, and sarin gas from their multi-use precursors, hydrogen cyanide, thioglycol, and glyphosate, respectively, and one on the potential bacterial production of the lethal natural product, saxitoxin.

The *Responsible Choices in Chemistry* section explores what it means to practice chemistry responsibly, as well as individual responsibilities of both chemists and non-chemists to understand and address the misuse of multi-use chemicals. Users first explore an individual role-playing scenario, where they have the option to choose what they consider to be



Group discussion during the IUPAC Congress in Istanbul, August 2013.

an appropriate response to a given scenario, and then continue to choose decisions in this way as the scenario continues to unfold, introducing deeper complexity and moral ambiguity. Following this, the user can explore both the successes and challenges of national and international efforts to regulate the production of chemical and biological weapons.

The third section, *Convergence of Chemistry and Biology*, explores the areas of overlap between the disciplines of chemistry and biology. The blurring of boundaries between chemistry and biology has enabled better understanding of biochemical pathways and exploited molecular biology for medical applications, and is also responsible for new industrial products and methods of production. However, this convergence also poses a new concern for chemical and biological warfare, especially when having two separate multi-lateral regimes for chemical and biological weapons leaves ambiguity as to the responsibility of each to monitor these convergent areas. Users explore the possible scenario of converting a brewery into a chemical weapons laboratory that uses genetically modified yeast to produce a chemical weapon. While this area of convergence has previously been largely unexplored, OPCW considered the implications of this convergence through a Temporary Working Group of the OPCW Scientific Advisory Board. This working group met four times between 2011 and 2013 to investigate the technological and scientific developments which are accelerat-



In WWI trench warfare, mustard gas was used against the Allied Forces.

ing the convergence of these disciplines. Their findings are available on the OPCW website.

The final section of the resource is *Codes of Conduct*, which explores the relevance of both aspirational and enforceable codes of conduct for the regulation and distribution of multi-use chemicals. This is implemented through the use of another interactive “decision tree,” as well as examples of the effects and power of various codes of conduct.

By interacting with the resource, users can engage in discussions of scientific ethics while learning or reinforcing chemistry concepts such as structure-function relationships. It is through this context-based learning that both chemistry information can be better communicated and the relevance of topics such as scientific ethics and codes of conduct can be more extensively understood and appreciated.

Resource for Workshops

The *Multiple Uses of Chemicals* resource has been piloted at several workshops for chemists and educators, including the August 2013 44th IUPAC World Chemistry Congress in Istanbul. The workshop, held just a week before the sarin incident in Syria, confronted participants with several role-playing scenarios, such as being a post-graduate student who is short of money but is familiar with the production of methamphetamine. Attendees were asked whether they would be curious to see if the synthesis was possible, whether they would tell others if they were successful, whether they would try again if they failed their first attempt at synthesis, and what circumstances would tempt them to sell the drugs. Participants discussed these questions in small groups, facilitated by the workshop directors, to see how innocent and seemingly harmless initial intentions can lead to dangerous or even criminal behaviour, all through a simple set of seemingly naturally connected decisions. The video of this workshop has been posted on the multiple-uses website, to give presenters tips for implementing the resource into their presentations and discussions. Another workshop was held at an OPCW regional meeting on responsible use of chemicals in Argentina in April 2014, and a workshop is planned for the 5th IUPAC Conference on Green Chemistry in Durban, South Africa, 17-21 August 2014. The resource is also being used in university contexts to provide ethics training for both undergraduate and graduate students in North America and Europe, and has been used with the Associate Programme at OPCW. 

Peter Mahaffy <peter.mahaffy@kingsu.ca> is Professor of Chemistry at the King's University College Edmonton, Canada, Co-director of the King's Centre for Visualization in Science, and Past-Chair of IUPAC's Committee on Chemistry Education. Joseph Zondervan is a fourth-year undergraduate chemistry student at the King's University College, and was the lead student researcher at the King's Centre for Visualization in Science, working on preparation of the Multiple Uses of Chemicals site. Alastair Hay <A.W.M.Hay@leeds.ac.uk> is Professor of Environmental Toxicology at the University of Leeds, England. He has worked on chemical weapons issues for more than 35 years and conducted six investigations of real and alleged chemical weapon use. Peter Mahaffy and Alastair Hay are members of the OPCW Temporary Working Group on Education and Outreach, and have worked together on developing and implementing educational materials related to multiple uses of chemicals since the 2005 Joint IUPAC/OPCW Oxford workshop. Daniel Feakes <Daniel.Feakes@opcw.org> is the Strategy and Policy Adviser in the Office of Strategy and Policy at the OPCW. He is the Secretary to the OPCW Temporary Working Group on Education and Outreach in Science and Technology Relevant to the Chemical Weapons Convention. Jonathan Forman <Jonathan.Forman@opcw.org> currently holds a post of science policy adviser at the OPCW. Prior joining OPCW in March 2013, Forman worked in Silicon Valley for several biotechnology companies developing molecular diagnostic and bioanalytical assay technologies for genomic, immunoassay, and cell capture applications.

Resources and References

1. Multiple Uses of Chemicals website: www.iupac.org/multiple-uses-of-chemicals or <http://multiple.kcvsc.ca/>
2. IUPAC Project 2013-020-1-050 “Updating, Piloting, and Disseminating Educational Material for Raising Awareness of the Multiple Uses of Chemicals and the Chemical Weapons Convention” www.iupac.org/project/2013-020-1-050
3. Multiple Uses of Chemicals: Choices for Chemists and the Public By Alastair Hay and Peter Mahaffy, *OPCW Today*, December 2013, Vol.2, No 5, pp. 23-24; www.opcw.org/documents-reports/opcw-today (the entire issue is on education and outreach and also includes a coverage of OPCW winning the Nobel Peace Prize)
4. Video message by OPCW Director-General Ahmet Üzümcü at the 44th IUPAC World Chemistry Congress in Istanbul, Turkey, which took place from 11 to 16 August 2013; www.youtube.com/watch?v=fWIX2IB8cSc (or via www.youtube.com/user/opcwonline)
5. Video of the workshop led by Dr. Alastair Hay and Dr. Peter Mahaffy at the IUPAC 44th World Chemistry Congress in Istanbul, August 2013 on how to use Multiple Uses of Chemicals in a workshop for chemistry educators; www.youtube.com/watch?v=HJ2psAWflso
6. IUPAC, OPCW, and the Chemical Weapons Convention by Leiv K. Sydnes, *Chemistry International*, July-August 2013, pp.4-8; DOI: 10.1515/ci.2013.35.4.4.