VOLUME 2 NUMBER 9

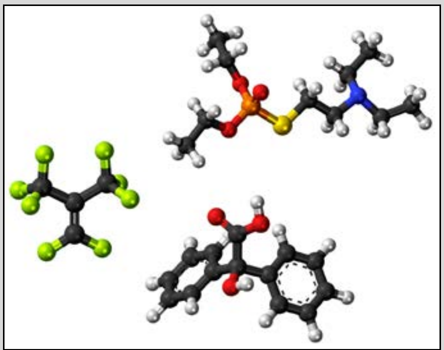
The OPCW Science & Technology Monitor

A sampling of Science & Technology Relevant to the Chemical Weapons Convention

13 August 2015

In This Issue

Featured content



Schedule 2 Chemicals

Image from World Water Monitoring Challenge.

Global science experiments

Image from Sparkfun.

A Carbon monoxide sensor

Welcome

Welcome to the *OPCW Science and Technology Monitor*, an occasional bulletin to provide updates on developments in science and technology across a broad spectrum of topics relevant to the CWC. Past issues are available from the Science and Technology section of the OPCW website.

Today marks the 55th anniversary of the first two-way telephone conversation by satellite (a balloon satellite called Echo 1) in 1960. One of many steps that have taken our communication technologies to where they are today and enabling so many opportunities for collecting and communicating information. To, further remind us of how far we have come, today is also the 126th anniversary of an 1889 patent for a coin-operated telephone, and we are certain that there will be many more telecommunication innovations to come.

The S&T Puzzle

We once again congratulate our friends at the CTBTO for finding all 25 words in last issues puzzle. The answers are shown below. Puzzle statistics now stand at: VER 4, OSP 2, OCS 1, INS 1 and CTBTO 5.

G	R	Z	Y	C	S	U	T	S	H	Q	W	N	C	C
D	G	D	R	R	C	B	P	O	A	A	R	O	A	O
N	M	N	O	V	I	P	K	D	X	I	N	I	N	S
O	G	U	S	L	E	L	S	G	A	I	S	S	N	M
C	I	F	I	T	N	E	I	C	S	T	N	S	A	E
E	W	F	V	Q	C	A	F	Y	C	M	E	E	B	T
S	K	H	D	Q	E	Y	R	U	L	U	W	S	I	I
S	B	O	A	R	D	T	D	X	T	N	S	U	N	C
C	R	O	W	D	S	O	U	R	C	I	N	G	O	S
W	C	P	O	I	R	D	E	T	A	L	E	R	I	W
C	I	R	M	P	U	Z	Z	L	E	U	V	J	D	N
Q	P	E	R	S	O	N	A	L	N	T	E	B	S	N
D	H	W	E	L	C	O	M	E	V	O	N	R	X	A
C	G	N	I	M	O	C	P	U	B	B	T	B	A	K
Y	T	N	E	W	T	H	B	Z	A	M	S	P	B	C

For this edition of the puzzle, we take inspiration from the "Astrobiological Periodic Table" and seek your inputs for a "Chemical Weapons Convention Periodic Table". We ask you to tell us how the elements of the periodic table are relevant in this context. Identify a link to the CWC for as many or as few elements as you like; points, equal to the sum of the atomic numbers of the elements identified, will be awarded. No points will be given for any element that is reported as having no relevance. Highest number of points scored wins the prize: a choice of requesting a featured topic, designing a puzzle, or receiving a beverage hand selected by the Science Policy Adviser. Send answers by email. Good luck!

Science Fun:

Hello Pluto! Last month, after a nine and a half year, 3 billion mile (that's 4.8 billion km) journey, astronomers celebrated as an unmanned vehicle called New Horizons reached Pluto, the last major *terra incognito* of our solar system (and how much do you know about pre-flyby Pluto?). The flyby took place on 14 July, fifty years to the day after another unmanned vehicle had been the first to reach Mars (that's right, we just celebrated the 50th anniversary of the first Mars flyby!). New Horizons represents everything we look for in an unmanned vehicle: fast (the average speed to get to Pluto was nearly 60,000 km/hour), capable of making chemical measurements and communicating with us from afar!

Image from Nasa.

Why do the images of Pluto appear red? Perhaps a consequence of the large amount of methane that is found there; cosmic rays and solar ultraviolet light can interact with this hydrocarbon to ultimately form tholins, which would explain the colour of the images.

Pluto is one of the coldest places in the solar system, with surface temperatures below -225ºC; plains covered by frozen nitrogen, methane and carbon monoxide; and mountains (some as high as 3500 meters) made of frozen water (and shorter mountain ranges have also been observed).

News and Updates

Recent reports and publications:

Report of the Twenty-Second Session of the OPCW Scientific Advisory Board.

UN Security Council Resolution 2235 (Adopted 7 August 2015) to establish a UN-OPCW Joint Investigative Mechanism.

Innovation and Diffusion of Green Technologies: The Role of Intellectual Property and Other Enabling Factors; a report on intellectual property and green technology from WIPO.

Bioenergy & Sustainability: Bridging The Gaps, report from Scientific Committee on Problems of the Environment (SCOPE).

Application of Modern Toxicology Approaches for Predicting Acute Toxicity for Chemical Defense, report from the US NAS.

Reimagining Human Health: 30 Innovations to Save Lives report from the IC2030 Initiative.

Reproducibility in life science research is an on-going issue, one with significant economic consequences. Improving inter-laboratory communication is recommended in one report; and guidelines for reporting have been created, however some scientists suggest these guidelines need more flexibility.

Science magazine special report on artificial intelligence.

July 2015 issue of Dstl's *inSIGHT*.

World Academy of Sciences (TWAS) newsletter, Volume 26 Issue 4.

Top 50 global chemical companies of 2014.

The game changing effect of new technology on finance. Report from the World Economic Forum.

An efficient and practical approach to biosecurity from the Centre for Biosecurity and Bioprepardness (Denmark).

Science and education resources:

Effective communication, to technical and non-technical audiences, is critical for productive engagement on science. Here are some tips for memorable presentations.

Building the 21st Century Scientist, the promise and challenges of bringing science, technology, engineering and mathematics (STEM) education in line with the lessons of education research.

Some news from world of science and technology:

From the weeks of 5 – 11, 12 – 18, 19 – 25 July, 26 July – 1 August and 2 – 8 August in chemistry.

Images show a large heart-shaped plain (of frozen carbon monoxide) alongside and the high frozen water mountains noted above; these features were named the Tombaugh Regio in honor of Pluto's discoverer Clyde Tombaugh.

The icy plains are scarred with long polygonal marks, dark streaks and rolling hills; challenging assumptions about geological activity on icy worlds; internal geological activity may be a possibility as heat appears to be coming from somewhere. Another intriguing feature of both Pluto and its largest moon, Charon, is their "youthful appearance" (crater free) which may have resulted from a collision between the two bodies.

Images reveal flowing glaciers of nitrogen and a haze extending over 130 km above the surface of the planet; a planet that appears to be "leaking nitrogen" at 500 tons per hour (from an atmosphere that reaches over 1,600 km above the surface). As New Horizons moves beyond Pluto, the spacecraft has already observed components of Pluto's atmosphere, carried off by solar winds, thousands of miles away.

There is much more is to look forward to over the next sixteen months (the time required to download all the data that has been collected), and even more fantastic discoveries are sure to follow as New Horizons moves onward. For those of you who can't wait the sixteen months, if you have a few minutes to spare to learn more about Pluto, take a look at the "Pluto in a Minute" video series.

July 2015 was quite a month for NASA: the Pluto flyby, the 50th anniversary of the 1st Mars flyby and no less significant, the 46th anniversary of the 1969 moon landing on 20 July (here's an article published in the 14 July 1969 issue of *Chemical and* Engineering News about the

Schedule 2 Chemicals

When we discuss chemicals relevant to the Chemical Weapons Convention (CWC), those falling under Schedule 1 tend to receive the most attention; yet, the number of possible chemical structures covered under Schedule 2 represents more chemicals than have actually been reported in the scientific literature! One just has to look at Schedule 2B(4) to see this. Have you ever wondered about the chemicals that fall under Schedule 2, why they are CWC relevant and what they are used for? Illustrating the importance of these chemicals beyond the CWC, in 2014, 1048 scientific journal articles and 1348 patents (applications and grants) involving Schedule 2 chemicals were published. Figure 1 summarises the publications, which were collected by SciFinder® searches through 1 June 2015. Figure 2 displays the collective abstracts in a word cloud to illustrate the words and themes across the publications.

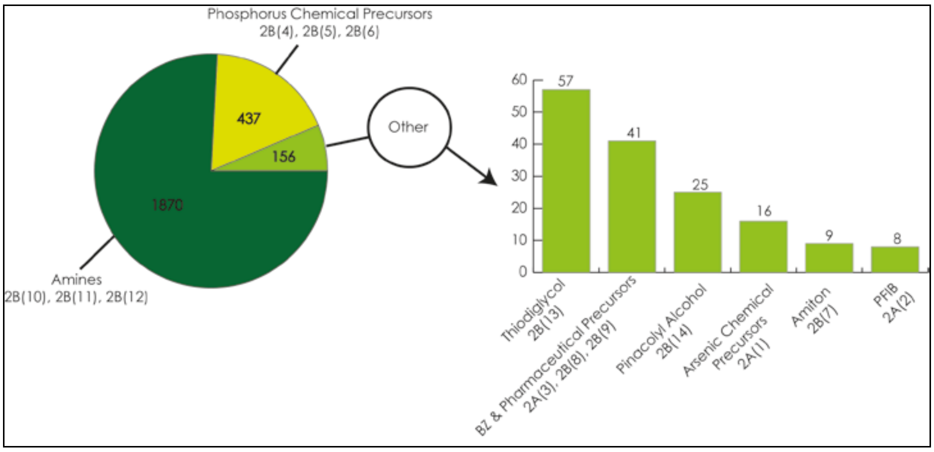


Figure 1: Number of publications (journal articles and patents) involving Schedule 2 Chemicals from 2014 (note that some publications concern more than one class of Schedule 2 chemicals – this has been corrected for within categories but not across categories).

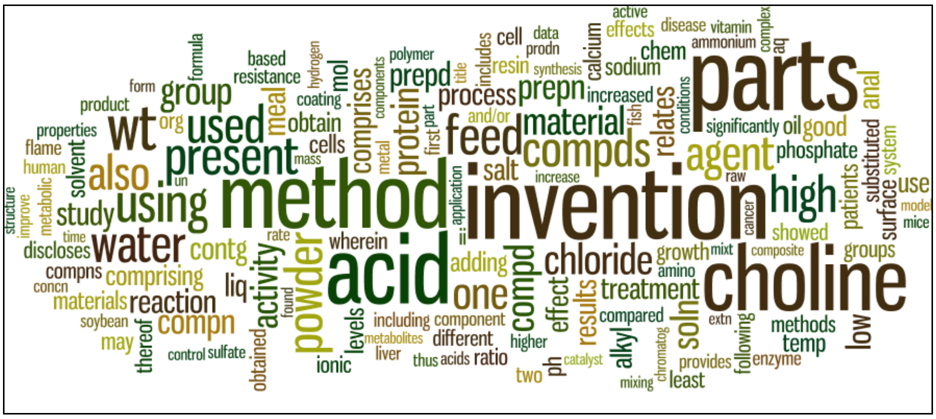


Figure 2: Word cloud of abstracts from journal articles and patents involving Schedule 2 chemicals published in 2014.

The following criteria are taken into account to consider whether or not toxic chemicals not listed in Schedule 1 and pre-cursors to chemicals in Schedule 1 or Schedule 2, part A would be listed in Schedule 2:

1. It poses a significant risk to the object and purpose of the Convention Weapons Convention because it possesses such lethal or incapacitating toxicity as well as other

Apollo 11 mission). We can only look forward to what comes next, no matter what it will be (perhaps a colony on the moon?), it is sure to capture the imagination.

Crowdsourcing:

Looking for a scanner that can recognise harmful ingredients in food. Do you have any ideas on how to build one? Take the food scanner challenge for a chance to win a European Union Horizon Prize.

Do you have ideas for a methodology that can identify the early indication of a climate or water event (such as a floods or drought) in one location triggering direct or indirect impacts in another location?

Help build a sustainable food system by creating an app with data from the USDA. This will help researchers, consumers and farmers understand the food supply, economic demand and remote sensing data.

Help NASA identify the features of Mars.

News from the (Twitter) crowd: an examination of civic media systems in wartime. To strengthen use of Twitter data to draw conclusions, this method of quantifying "controversy" might also be helpful.

Upcoming S&T Related Events:

10 - 14 August 2015
Biological Weapons Convention Meeting of Experts.
Geneva, Switzerland.
Daily reports are now available.

16 – 20 August 2015
250th American Chemical Society National Meeting and Exhibition.
Boston, MA, USA.

properties that could enable it to be used as a chemical weapon;

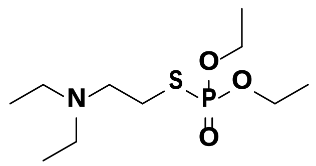
2. It may be used as a precursor in one of the chemical reactions at the final stage of formation of a chemical listed in Schedule 1 or Schedule 2, part A;

3. It poses a significant risk to the object and purpose of the Chemical Weapons Convention by virtue of its importance in the production of a chemical listed in Schedule 1 or Schedule 2, part A;

4. It is not produced in large commercial quantities for purposes not prohibited under the Chemical Weapons Convention.

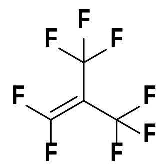
We continue with an overview of Schedule 2, parts A (Toxic Chemicals) and B (Precursors). In regard to uses of these chemicals for purposes not prohibited under the Chemical Weapons Convention, Figures 3 and 4 categorize the 2014 publications by topical area.

Schedule 2 Part A, Toxic Chemicals



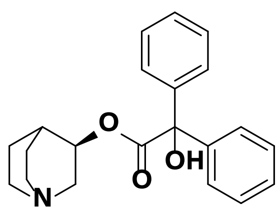
Amiton
2A(1)

Schedule 2A(1): Amiton (VG, *O*,*O*-Diethyl *S*-[2-(diethylamino)ethyl] phosphorothiolate) and its corresponding alkylated or protonated salts. Amiton was originally produced as an insecticide, but was later determined to be too toxic for agricultural use.



PFIB
2A(2)

Schedule 2A(2): 1,1,3,3,3-Penta-fluoro-2-(trifluoromethyl)-1-propene (PFIB), a lung toxic agent that has seen development for use as a chemical weapon.



(R)-(-)-3-Quinuclidinyl benzilate
2A(3)

Schedule 2A(3): 3-Quinuclidinyl benzilate (BZ), an anticholinergic agent that was developed as a psychomimetic chemical weapon in the 1960s. This bioactive chemical can also be used as a building block for other more complex therapeutic compounds.

Schedule 2 Part B, Precursors

Schedule 2B(4): This Schedule covers chemicals, except for those listed in Schedule 1, containing a phosphorus atom to which is bonded one methyl, ethyl or propyl (normal or iso) group but not further carbon atoms. There are an infinite number of possible structures that can fit this description. Compounds that are precursors and degradation products (methylphosphonic acid for example) of Schedule 1 nerve agents fall under this Schedule. The Schedule makes an exemption for Fonofos, an insecticide that was widely used on corn at the time the convention was signed.

24 – 27 August 2015
FinMedChem 2015.
Helsinki, Finland.

31 August – 4 September 2015
Sixth Summer Programme on Disarmament and Non-Proliferation of Weapons of Mass Destruction (WMD) in a Changing World Disarmament and Non-Proliferation of Weapons of Mass Destruction (WMD) in a Changing World. Asser Institute, The Hague, The Netherlands.

3 – 4 September 2015
The International Conference On Chemical Sciences And Engineering (CHEMSCIE 2015).
Veracruz, Mexico.

6 - 10 September 2015
The European Conference on Analytical Chemistry (EUROANALYSIS 2015)
Bordeaux, France

9 - 11 September 2015
Wait What? A Future Technology Forum. Saint Louis, MO, USA.

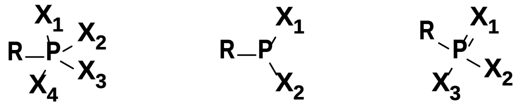
13 - 15 September
Trends Symposium IAP Biosecurity Working Group. Warsaw, Poland

13 – 16 September
1st International Workshop on Mobile Learning (WmL'15).
Lodz, Poland.

20 – 24 September 2015
9th International Conference on Instrumental Methods of Analysis-Modern Trends and Applications (IMA2015). Kalamata, Greece.

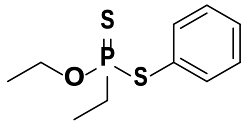
27 September – 1 October 2015
ECCE10 (10th European Congress of Chemical Engineering); ECAB3 (3rd European Congress of Applied Biotechnology); and EPIC5 (5th European Process Intensification Conference)
Nice, France.

5 - 8 October 2015
SOLVE. Cambridge, MA, USA.



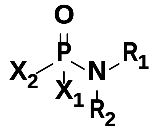
2B(4)

R= Me, Et, *n*-Pr or *i*-Pr
X_1, X_2, X_3, X_4 = Any group not attached to the Phosphorous atom through a Carbon



Fonofos

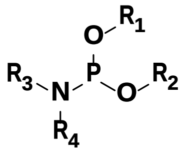
Schedule 2B(5): *N*,*N*-Dialkyl (Me, Et, *n*-Pr or *i*-Pr) phosphoramidic dihalides; compounds that can serve as intermediates in the preparation of nerve agents.



R_1, R_2= Me, Et, *n*-Pr or *i*-Pr
X_1, X_2= Halogens

2B(5)

Schedule 2B(6): Dialkyl (Me, Et, *n*-Pr or *i*-Pr) *N*,*N*-dialkyl (Me, Et, *n*-Pr or *i*-Pr)-phosphoramidates; compounds that are formed as co-products in the synthesis of Tabun class nerve agents. Compounds in this Schedule, as well as those of 2B(5), are of interest for their fire resistant properties.

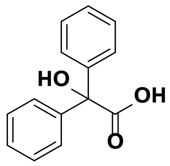


R_1, R_2'R_3, R_4= Me, Et, *n*-Pr or *i*-Pr

2B(6)

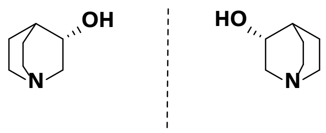
Schedule 2B(7): Arsenic trichloride ($AsCl_3$), a compound that can be used as a precursor for lewisites and other arsenic containing chemicals; including fluorescent probes (which can be attached to quantum dots and surfaces) for protein analytics.

Schedules 2B(8), 2,2-Diphenyl-2-hydroxyacetic acid; and **2(B)9,** Quinuclidin-3-ol; are precursors of BZ and other bioactive compounds. Quinuclidin-3-ol has also been used to prepare amine mixtures for carbon dioxide capture.



2,2-Diphenyl-2-hydroxyacetic acid

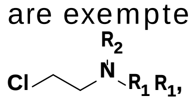
2B(8)



(S)-(+)-3-Quinuclidinol (R)-(+)-3-Quinuclidinol

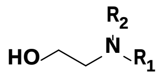
2B(9)

Schedules 2B(10), *N*,*N*-Dialkyl (Me, Et, *n*-Pr or *i*-Pr) aminoethyl-2-chlorides and corresponding protonated salts; **2B(11),** *N*,*N*-Dialkyl (Me, Et, *n*-Pr or *i*-Pr) aminoethane-2-ols and corresponding protonated salts; and **2B(12),** *N*,*N*-Dialkyl (Me, Et, *n*-Pr or *i*-Pr) aminoethane-2-thiols and corresponding protonated salts; are amino compounds that can be both pre-cursors and degradation products of Schedule 1 chemical agents. These compounds make up over 75% of the 2014 publications illustrated in Figure 1; their uses spanning a broad range of applications (as shown in Figures 3 and 4). *N*,*N*-Dimethyl- and *N*,*N*-Diethyl-aminoethanol and their corresponding protonated salts are exempted from Schedule 2B(11).



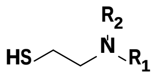
R_2= Me, Et, *n*-Pr or *i*-Pr

2B(10)



R_1, R_2= Me, Et, *n*-Pr or *i*-Pr

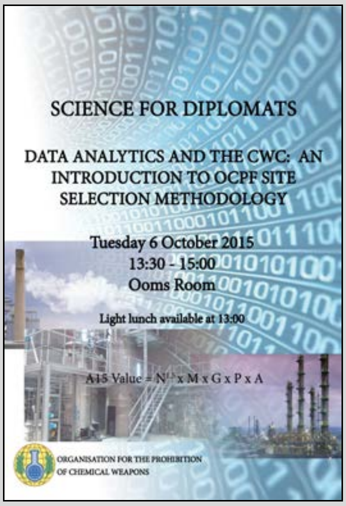
2B(11)



R_1, R_1= Me, Et, *n*-Pr or *i*-Pr

2B(12)

6 October 2015
"Science for Diplomats".
OPCW Headquarters, The Hague, Netherlands.



15 October 2015
Smart Manufacturing Summit.
Livermore, California, USA.

31 October - 2 November 2015
The Port Hackathon.
CERN

4 – 7 November
World Science Forum.
Budapest, Hungary.

16 – 19 November 2015
Malta Conference.
Rabat, Morocco.

18 – 21 November 2015
16th Asian Chemical Congress.
Dhaka, Bangladesh.

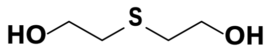
22 – 27 November 2015
2nd African Conference on Research in Chemical Education (ACRICE)
University of Venda, Thohoyandou, South Africa.

23 – 25 November 2015
XIIIth International Symposium on Environment, Catalysis and Process Engineering (ECGP'13)
Hammamet, Tunisia.

14 – 18 December 2015
Biological Weapons Convention Meeting of States Parties.
Geneva, Switzerland.

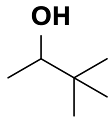
15 – 20 December 2015
Pacifichem 2015.
Honolulu, Hawaii, USA.

Schedule 2B(13): Thiodiglycol, the precursor (and also a hydrolysis product) of sulphur mustard. Uses of this compound include inks and dyes. A recent patent made use of this chemical in a process to render tissue samples transparent.



Thiodiglycol: Bis(2-hydroxyethyl)sulfide 2B(13)

Schedule 2B(14): Pinacolyl alcohol, a precursor for soman. This alcohol may also have applications in the stabilization of gas hydrates, making it a candidate for use in carbon dioxide sequestration.



Pinacolyl alcohol
2B(14)

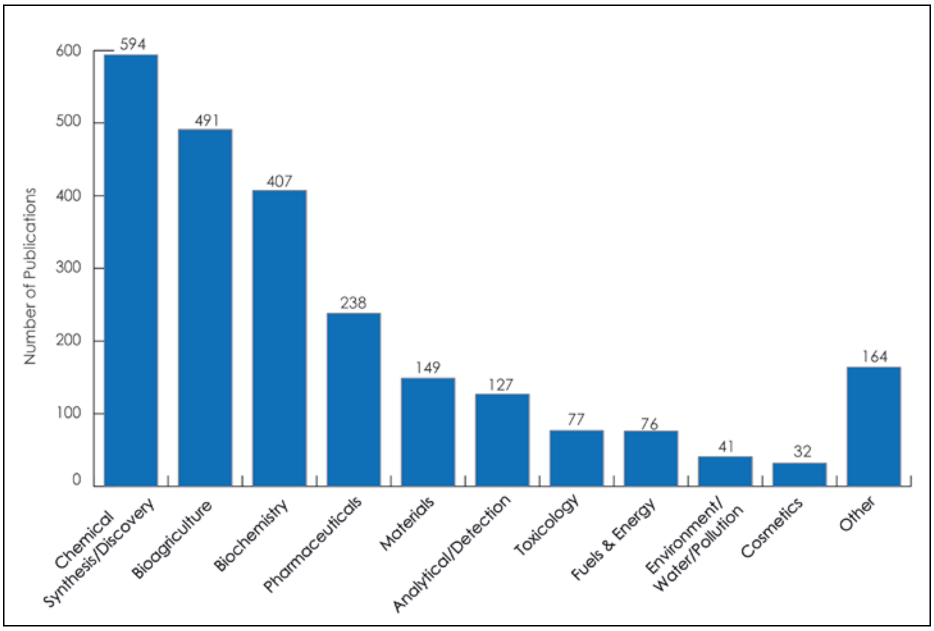


Figure 3: The number of publications from 2014 concerning Schedule 2 chemicals categorized by topical area.

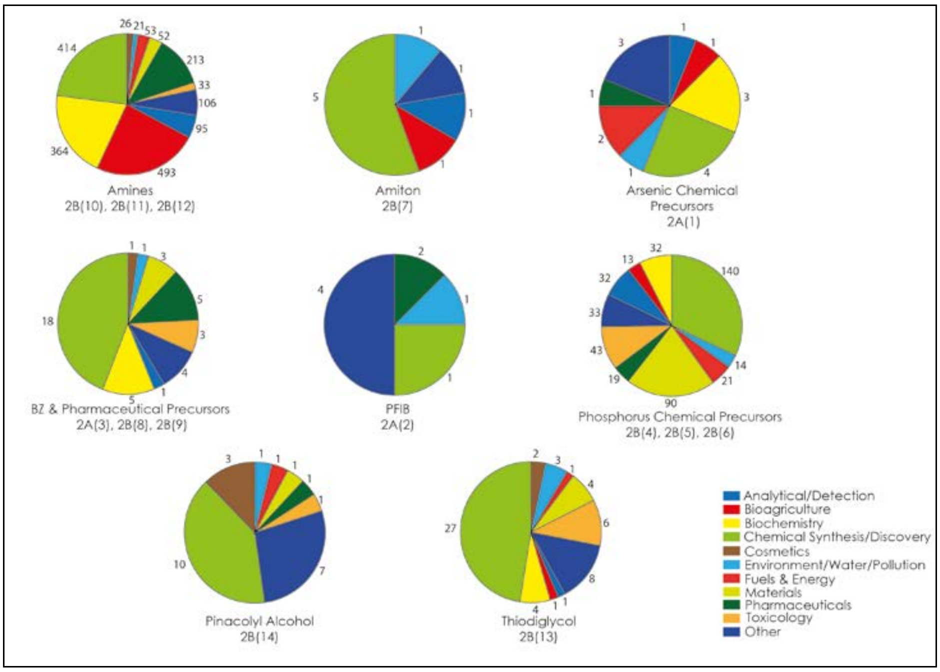


Figure 4: 2014 publications categorized by topical area for individual (and similar) classes of Schedule 2 chemicals.

Contact Us:

Questions, ideas, comments, suggestions, want to make a contribution, or be added to the mailing list? Please contact us through the OPCW Office of Strategy and Policy (OSP).

For more frequent updates, Visit us on the web or follow us on Twitter at @OPCW_ST.

Citizen Science

Our world is increasingly more "connected" through devices that make measurements, store data, facilitate communication and open up untold possibilities for how we live and work. A connected world facilitates new and more global ways to collaborate, to harness the power of "the crowd" and to participate in scientific endeavours without needing a specialised degree or even access to a laboratory. In effect, anyone can collect and analyse data, and participate in the scientific process. Scientific projects that involve the crowd strategy, generally relying on volunteer participation, are often called "Citizen Science". The crowd sourced approach can even be implemented through engagement of those involved in activities such as biking and surfing! Using citizens and smartdevices to monitor the structural health of urban infrastructure has also been proposed.

"Crowds" have been engaged for observing weather, astronomy (including projects where space agencies provide data to citizens), preventative medical research, studying biodiversity (building distribution models of animal species for example), monitoring bees, reporting of invasive species, mapping radiation levels, water and other environmental monitoring (by recording observations and/or making chemical or physical measurements). Crowd based projects can serve as a platform for education and awareness raising of environmental issues such as water quality (with global reach); some environmental projects have actually resulted in the creation of monitoring networks, identification of violators of pollution laws and when combined with other data sources have resulted in legal initiatives. Citizen science projects can also provide mechanisms to accelerate digitization and archiving of scientific collections.

There have always been opportunities for citizens to participate in scientific pursuits. Our connected world has opened up such opportunities by making them more accessible to a broader spectrum of people. Organisations such as the Citizen Science Association, the European Citizen Science Association and Citizen Science Network Australia provide forums for practitioners to engage with one another. Zooniverse, CitSci.org, Wildbook and SciStarter provide infrastructure to host projects and connect scientists with citizens. There are also forums focused on specific activities including sensor based projects and teaching citizens how to engage in environmental monitoring. Science museums and governmental bodies (the European Union for example) also organise citizen science projects; if interested we encourage you to seek out opportunities, especially with science museums, in your local area.

As with any scientific activity, questions concerning qualifications of participants (and how these vary), validity of the data collection method, validity of the data itself and the robustness of the conclusions all need to be addressed. Data management is very important to think through, prompting some to call for the standardization of metadata language to facilitate more efficient sharing of information across projects. To help, practitioners have taken the lessons learned from previous studies and produced guides, manuals and recommendations for best practices, as well as guidelines for data quality and ethical considerations.

The availability of tools to make measurements is key to successful crowd engagement. In this regard, simply having a Smartphone (or multiple Smartphones) opens up opportunities. Examples include Smartphone microscopes and Apps for ecology. As new Smartphone capabilities come forth (ultrasonic fingerprint reading for example, details here), citizen science projects will certainly find clever ways to employ them.

For environmental monitoring, a wealth of possibilities are now available through low cost sensor technologies (using kits to build customised sensors or by using commercially available devices), which we will further elaborate in the feature that follows.

The ability to miniaturize analytical tools has generated interest in portable scanners for food (to detect allergens), with monetary awards available for working tools and companies developing products.

For health related projects, infectious disease surveillance data can easily be collected in rural locations with Smartphones, and a project like ResearchKit provides Apps for iPhones to gather medical data. Of course, the growing trend in personal health and wearable fitness monitors is generating questions about measurement accuracy (which are especially important in regard to concerns raised about do-it-yourself healthcare).

We have previously looked at the use of Smartphones as scientific instruments and diagnostic tools. However, more advanced cellular, biomolecular or clinical measurements require laboratory training, laboratory equipment and/or specialty reagents, which are impractical for many citizen science initiatives. Providing passive sampling devices that absorb chemicals and are sent to a lab for analysis (wearable wristbands for example) provide a means to overcome such limitations. Likewise, the idea of volunteers sending samples to laboratories for analysis has seen use in commercial endeavours for product development.

Gamification can be an effective method for engaging the crowd. This is the use of games which are designed to be fun and to remove the barriers to understanding the underlying science. In effect, scientific knowledge can be generated simply by aligning coloured blocks to perform multiple sequence alignment or looking at the connectivity of tangled objects to map the brain.

Open source scientific tools, internet based communities and even access to 3D printing provide additional opportunities for low cost science resources (telescopes for example). Other projects are enabled through sharing of ideas and expertise across participants – take for example a project for monitoring biodiversity of a lake involving scientists, naturalists and drone technology developers.

We conclude by pointing out that the crowd can also be engaged to fund science projects, through resources such as Experiment or Kickstarter (infamous in some circles for the glowing plant project of 2013).

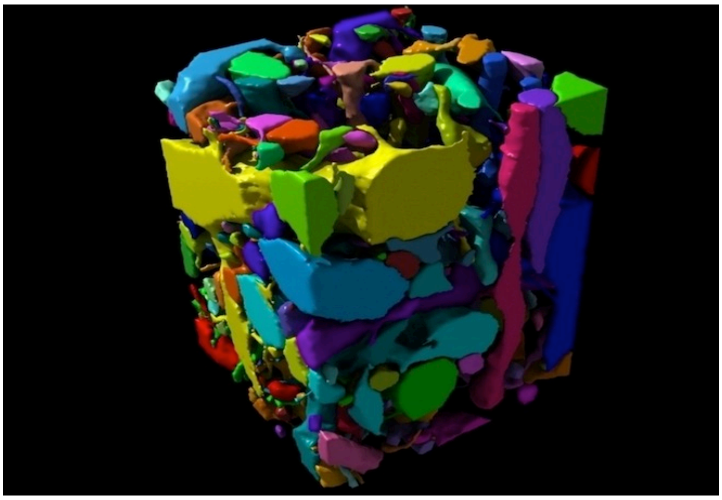


Image from EyeWire.

A recent example, related to sensors and citizen science: a university project combining gas sensors with small drones for pollution monitoring.

Sensors for Citizens

Of all the tools employed in citizen science projects, simple and low cost environmental sensors (specifically for air and water sampling) are of the most interest to us; these types of sensors being relevant to the chemical informatics project under EU Council Decision (CFSP) of 17 February 2015 Project III. Mobile sensors with the ability to collect and transmit data can augment environmental data collected across networks of more traditional expensive (and non-mobile) systems; a concept that has been described in reports from the United States Environmental Protection Agency (EPA). The EPA website includes resources on both air and water monitoring.

For those who like to tinker, open-source electronics are ideal. There are a wealth of do-it-yourself options and guide books for making and programming sensors available. Open-source electronics can also create gadgets to act as sensor platforms (likewise, cars can be used in this capacity too). Arduino (often in combination with Raspberry Pi computers) is one of the more popular platforms for open-source electronic prototyping (with kits and components are available from vendors such as Adafruit and Sparkfun). Arduino systems have been used to produce air sensors, pH meters for ocean water studies and microspectrometers. They also can be integrated with more complex analytical chemistry equipment (automation to assist mass spectrometry for example). With the proper tools, electrochemical sensors are also possible (details here). Home automation and the "internet of things" may offer additional capabilities that can be combined into sensor systems.

For those who prefer to buy ready to use technology, an appendix with a table containing examples of portable commercially available sensors is attached. The accuracy, precision and reliability of these devices will vary with how they are used; what makes them valuable is the easy access they provide for citizen science and educational initiatives related to chemical measurement. Guidebooks for evaluating and choosing suitable sensors for various applications are available.

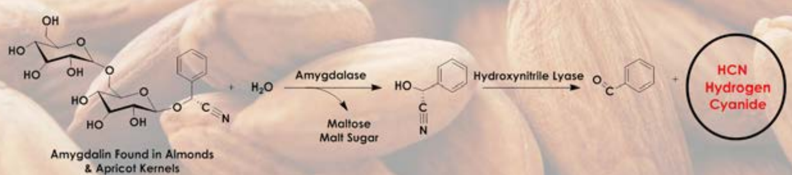
In regard to chemistry education, measurement of chemicals in air pollution or of water quality parameters can generate data sets with signal, temporal and geographic dimensions. Such data could be compared to independently measured data sets with similar (or identical) temporal and geospatial information. The source of comparison data might be from an environmental monitoring system (for those of us in The Hague, this could be the air quality network of the Netherlands).

Airqualityegg, a commercial air monitor lets you connect to a global data monitoring system

There is no expectation for the data sets to correlate, however, the measurements and their comparisons could be integrated into laboratory coursework intended to introduce and explain important concepts in analytical science: accuracy, precision, uncertainty, correlation, differences between measuring devices (and/or locations) as well as statistical treatments of measurement data. Low cost sensors are ideally suited for these purposes; with the open-source electronics platforms expanding the educational potential.

Did You Know?

Digesting an almond can produce hydrogen cyanide?



Appendix to *OPCW Science & Technology Monitor* Volume 2, Number 9: Examples of commercially available portable chemical sensors.

Sensor	Sampling	Sensor Used for Chemical Measurements*	Chemical Measurements	Description
Hydrolab DS5	Water	Optical light scattering fluoresce Electrochemical	ammonium nitrate chloride rhodamine WT chlorophyll a total dissolved gas (TDG)	 Profiling or unattended long term data collection.
Hydrolab MS5	Water	Optical light scattering fluoresce Electrochemical	ammonium nitrate chloride rhodamine WT chlorophyll a total dissolved gas (TDG)	 Profiling or unattended long term data collection
Hydrolab Quanta G	Water	Electrochemical Conductivity	Dissolved oxygen pH	 Measures 8 different water quality parameters.
smarTROLL	Water	Electrochemical Conductivity	Dissolved oxygen pH	 Works with mobile device and measures other physical parameters.
Seneye Reef	Water	Electrochemical Conductivity	ammonia pH	 Aquarium monitor.

***Some of the devices may also measure temperature, humidity, particulates and/or light exposure. Sensors for these measurements are not listed.**

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Sensor	Sampling	Sensor Used for Chemical Measurements*	Chemical Measurements	Description
MQ Gas Sensors	Air	Metal oxide semiconductor	carbon monoxide hydrogen hydrogen sulfide alcohol volatile organic compounds (VOC)	 Multiple sensors that interface with Arduino kits are available(MQ-7 Carbon monoxide sensor shown above)
Aeroqual series 500	Air	Multiple types of sensors are available	30 different gas sensors are available	
NEXTtoME	Air	Electrochemical Optical	carbon monoxide alcohol	 Can be linked to mobile devices via Bluetooth.
Q-trak Indoor AQM	Air	Electrochemical Non-dispersive infrared (NDIR)	carbon dioxide carbon monoxide volatile organic compounds (VOC)	

***Some of the devices may also measure temperature, humidity, particulates and/or light exposure. Sensors for these measurements are not listed.**

Appendix to *OPCW Science & Technology Monitor* Volume 2, Number 9: Examples of commercially available portable chemical sensors.

Sensor	Sampling	Sensor Used for Chemical Measurements*	Chemical Measurements	Description
Cube	Air	Electrochemical	carbon monoxide	
Foobot	Air	Metal oxide semiconductor	carbon dioxide carbon monoxide volatile organic compounds (VOC)	 Signal processing converts VOC levels to CO_2 equivalents. Links to mobile devices.
Airqualityegg	Air	Metal oxide semiconductor	carbon monoxide nitrogen dioxide ozone	 Connects to an existing global monitoring system
Langan DataBear T15v	Air	Electrochemical	carbon monoxide	
SCIO Spectrometer	Multiple	Near Infrared Spectrometer	750 nm - 950 nm	 Links to mobile devices.

***Some of the devices may also measure temperature, humidity, particulates and/or light exposure. Sensors for these measurements are not listed.**