Twenty-Sixth Session
16 – 20 October 2017

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REPORT OF THE SCIENTIFIC ADVISORY BOARD'S WORKSHOP ON EMERGING TECHNOLOGIES

1. EXECUTIVE SUMMARY

1.1 The OPCW Scientific Advisory Board (SAB) in cooperation with the International Union of Pure and Applied Chemistry (IUPAC),[1] The National Academies of Science, Engineering and Medicine of the United States of America (NAS),[2] the Brazilian Academy of Sciences (ABC),[3] and the Brazilian Chemical Society (SBQ)[4] held a workshop,[5] "Innovative Technologies for Chemical Security", from 3 to 5 July 2017 in Rio de Janeiro, Brazil.[6] The workshop was the third of a series intended to inform the report of the SAB on developments in science and technology to the Fourth Review Conference[7] of the Chemical Weapons Convention (hereinafter, "the Convention") to be held in December 2018. The workshop explored the potential of new technologies to enhance capabilities necessary for implementation of the Convention. The thematic content was based on findings that arose through the report of the OPCW SAB's Temporary Working group (TWG) on Verification.[8]

1.2 The emergence and practical applications of new and innovative technologies, as well as the repurposing of existing technologies for unanticipated new applications, has

1 For additional information on IUPAC, see: https://iupac.org/

2 The National Academies of Science, Engineering and Medicine (NAS). For additional information on NAS, see: http://www.nationalacademies.org/index.html

3 Academia Brasileira de Ciências (ABC). For additional information on ABC, see: http://www.abc.org.br/rubrique.php3?id_rubrique=2

4 Sociedade Brasilia de Química (SBQ). For additional information on SBQ, see: http://www.abc.org.br/rubrique.php3?id_rubrique=2

5 Funding for the workshop was provided in part through Project III (Science and Technology: Assessment of Developments in Science and Technology) of EU Council Decision (CFSP) 2015/259 dated 17 February 2015.
http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2015.043.01.0014.01.ENG

6 See also (a) Scientists review innovative technologies for chemical security, www.opcw.org/news/article/scientists-review-innovative-technologies-for-chemical-security/; and (b) Ciência para a paz, http://www.abc.org.br/centenario/?Ciencia-para-a-paz (in Portuguese).

7 Fourth Special Session of the Conference of the States Parties to Review the Operation of the Chemical Weapons Convention.

8 Verification, Report of the Scientific Advisory Board's Temporary Working Group (SAB/REP/1/15, dated June 2015). Available at:
www.opcw.org/fileadmin/OPCW/SAB/en/Final_Report_of_SAB_TWG_on_Verification_-_as_presented_to_SAB.pdf

benefited from increasingly transdisciplinary approaches to problem solving and technology development across scientific communities. This convergence across traditional disciplinary boundaries fuels the "rapid pace of developments in science and technology" that is often discussed within chemical and biological security communities.[9] New advances across the chemical and biological sciences are increasingly enabled by ideas and tools originating from sectors outside these disciplines, and Convention relevant developments in science and technology may not be easily recognised if the scientific review process is limited to chemical-specific fora. Information and communication technologies play a key role across 21st century scientific development, and the integration of these technologies with (bio)chemical, spatial, temporal and other data streams have potential applications in chemical security; including the ability to recognise unexpected or unusual chemical and biochemical changes in the environment in real time. Detectable changes from exposure to chemical agents might be sensed using remote monitoring and automated systems. Such integrated technologies might enhance capabilities in both early warning and investigation.

1.3 Given the rapid pace of scientific advancements combined with readily accessible mobile technologies, and unprecedented access to and diffusion of transdisciplinary (convergent) scientific knowledge, it is understandable that concerns about the multi-use potential of new science will arise. However, there is also a need for practical considerations to ensure that the science review process recognises opportunities made available through innovative approaches to technology development and application. In this regard, the adoption of new methods and technologies (especially informatics, mobile device, robotics and remote sensing technologies) for non-proliferation purposes is an emerging field.[10] A field in which it is recognised that overcoming and responding to challenges in disarmament can benefit from seizing opportunities provided through technological advancement and innovation.

1.4 In response to the need for recognition of opportunity from emerging scientific developments, experts in sensor development, precision agriculture, mobile and wearable technologies, digital health, autonomous sample collection and analysis, satellite image analysis, and technologies that enable real time analysis and decision making were brought together. The participants discussed capabilities, applications and challenges in the use of new tools and technologies to detect biochemical change

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9 See for example: (a) Spiez CONVERGENCE Report on the first workshop, Spiez Laboratoy, 2014; available at: https://www.labor-spiez.ch/pdf/de/rue/Spiez_Convergence_2014_web.pdf (b) Spiez CONVERGENCE Report on the second workshop, Spiez Laboratoy, 2016; available at: https://www.labor-spiez.ch/pdf/en/rue/LaborSpiezConvergence2016_02_FINAL.pdf

10 See for example: (a) New Nonproliferation & Disarmament Verification Technology, MIIS James Martin Center for Nonproliferation Studies, http://www.nonproliferation.org/new-technology-in-treaty-verification/ (b) New Media Solutions in Nonproliferation and Arms Control: Opportunities and Challenges; B. Lee, M. Zolotova; MIIS James Martin Center for Nonproliferation Studies, 2013. Available at: http://www.nonproliferation.org/wp-content/uploads/2014/02/140204_new_media_online_societal_verification.pdf (c) Innovation in countering weapons of mass destruction; A. Weber, C. L. Parthemore; *Arms Control Today*, July/August 2015, https://www.armscontrol.org/ACT/2015_0708/Features/Innovation-in-Countering-Weapons-of-Mass-Destruction (d) Recruiting Silicon Valley to join the fight against WMD threats, R. Gottemoeller, 2016, https://medium.com/@RGottemoeller/recruiting-silicon-valley-to-join-the-fight-against-wmd-threats-bf7ffea62430#.sl26u8vuu

in complex environments, and considered their potential applications to support chemical disarmament.

1.5 The workshop was chaired by Dr Christopher Timperley (OPCW SAB Chairperson). Dr Mark Cesa (IUPAC Past President), Dr Timperley, Professor Luiz Davidovich (President of ABC), Professor Aldo Zarbin (President of SBQ) and Dr Jonathan Forman (OPCW Science Policy Adviser and Secretary to the SAB) opened the workshop, introducing their respective organisations, welcoming the participants, and providing an overview of the programme and its intended outcomes.

1.6 From the workshop discussions, the following outcomes are submitted for consideration by the SAB at its Twenty-Sixth Session in October 2016:

(a) The practice of bringing together international transdisciplinary groups to share and discuss ideas is vital for meeting future challenges. This practice has been a valuable part of OPCWs science and technology review process, and the Secretariat and SAB are encouraged to continue this approach when considering scientific and technological advancements. *See paragraph 14.5*.

(b) Through the science and technology review process, the SAB has identified a variety of innovative technologies and technology developers. The SAB could usefully facilitate engagement with these communities. *See paragraphs 14.2(d), 14.3(d), and 14.5(a)(b).*

(c) A broad set of technology exists that can potentially find application in some areas of implementation of the Convention. In general, such tools appear best suited toward non-routine (contingency) and/or assistance and protection operations, investigations, enhancement of laboratory capabilities,[11] and stakeholder engagement. *See paragraphs 5.5(b), 5.6, 5.7, 6.4(b), 14.2, and 14.4(a).*

(d) Technologies that integrate informatics tools, mobile devices and remote sensing with an expanding range of capabilities are becoming increasingly accessible. The Convention's science review process should continue to keep abreast of developments in these areas. *See paragraphs 10.5(a), 14.2(d), and 14.3(c).*

(e) The Secretariat might consider outreach strategies, such as crowd source competitions to engage and gain access to innovative technologies and ideas. Engaging relevant innovators to participate in Convention-related training and familiarisation would provide an additional avenue to reach out to innovation communities. *See paragraphs 14.2(d), 14.3(d), and 14.5.*

(f) A number of the technologies considered during the workshop have potential for reducing risks to personnel operating in dangerous environments. Further consideration of these technologies could assist with development of

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11 "Upgrading The OPCW Chemical Laboratory to a Centre for Chemistry and Technology", S/1512/2017, dated 10 July 2017.

recommended best practices for operating under such conditions. *See paragraphs 5.6, 10.5(c)(d), and 14.2.*

(g) Many interesting and potentially enabling technologies were discussed at the workshop. It should be emphasised that suitability for field use requires evaluation of fieldable capabilities that meet operational requirements (and fit within mission specific modalities). Opportunities to engage with technology developers and evaluate new tools should be encouraged. *See paragraphs 5.5(b), 5.7(d), 8.3(b), 14.2(c)(d), 14.3(d),14.4 and 14.5.*

(h) The insight brought into discussions by chemical weapons inspectors regarding fieldable and operational needs and challenges is an essential aspect of recognising opportunities where a given technology might prove valuable. The practice of engaging operational staff from the Secretariat in the scientific review process aids the formulation of practical science advice, and also allows the SAB to provide scientific guidance on operational practices. The Secretariat is encouraged to maintain this discourse with the SAB. *See paragraphs 5.5(a), 5.7(a), and 14.5(c).*

2. AGENDA ITEM TWO – Adoption of the agenda

The workshop adopted the following agenda:

1. Opening of the session

2. Adoption of the agenda

3. Introduction of participants

4. Establishment of a drafting committee

5. Emerging technologies and implementation of the Chemical Weapons Convention

   (a) Contingency operations - challenges for OPCW inspectors

   (b) Aerial platforms for reconnaissance, sample planning and basic detection

6. Recognising biochemical change: *if plants could talk*

   (a) Remote sensing of terrestrial ecosystems

   (b) Technologies being adopted for precision agriculture and their potential applications

   (c) Optical sensors for the detection of biophysical and biochemical changes of plants: Case studies from plant-pathogen interactions

7. Recognising biochemical change: *large scale environmental monitoring*

On-site data fusion – satellites and dispersion models: The 2016 Al-Mishraq sulphur plant fire

8. Recognising biochemical change: *chemical sensing*

(a) Targeted catalytic degradation of organophosphates: pursuing sensors

(b) Multisensor systems (eNose) for toxic gases detection and biomedical applications

9. Mobile and wearable technologies and point-of-care devices

(a) Flexible, foldable, and wearable paper-based electronics and electrochemical devices

(b) Wearable technology for chem/bio: existing and emerging capabilities

10. Digital health

(a) Digital health: what you can learn from your Smartwatch

(b) Understanding smart data collection vs. Big Data collection and how to focus artificial intelligence (AI) analysis

11. Collecting data in remote and dangerous environments

(a) Unmanned airborne mass spectrometer (UAS-MS) for autonomous *in-situ* chemical measurements under harsh environment conditions

(b) Collection and processing of biological samples in remote and dangerous places; the environmental sample processor (ESP) as a case study

(c) Modular robotic toolbox for counter-CBRN[12] support

(d) Unmanned aerial vehicle equipped with CBRN detection, identification and monitoring (DIM) capability to enhance chemical awareness

12. International monitoring

(a) Monitoring networks tracking biogeochemical changes in coastal and maritime environments from Argentina

(b) Remote sensing and open-source research for non-proliferation analysis: case studies from the Middlebury Institute of International Studies, Center for Nonproliferation Studies

[12] CBRN = Chemical, Biological, Radiological and Nuclear.

13. Computer aided engineering tools applied to Implementation of the Convention

14. Breakout groups

    (a) Enhancing the capabilities of inspectors

    (b) Standoff detection and early warning systems

    (c) Collecting and integrating data streams – is there a need in implementation of the Convention?

    (d) Opportunities for new technologies in the implementation of the Convention

15. Closing remarks

16. Adoption of the report

3. AGENDA ITEM THREE – Introducing workshop participants

A list of participants appears in the Annex of this report.

4. AGENDA ITEM FOUR – Establishment of a drafting committee

A drafting committee of SAB members was formed to prepare the draft report of the workshop.

5. AGENDA ITEM FIVE – Emerging technologies and the implementation of the Chemical Weapons Convention

5.1 The workshop began with an introduction to the work of the SAB, the relevance of emerging and new technologies in the science and technology review process, and the mechanism through which recommendations are made by the SAB. This was followed by perspectives from inspectors on capabilities and challenges in their work. The session was moderated by Dr Mark Cesa.

Subitem 5(a): Contingency operations - challenges for OPCW inspectors

5.2 Beginning with the 2013 United Nations led mission in the Syrian Arab Republic,[13] the Technical Secretariat (herein after, "the Secretariat") has undertaken non-routine inspection, verification and technical assistance activities in the Syrian Arab Republic,[14] Libya[15] and Iraq. These contingency operations increasingly require

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13 United Nations Mission to Investigate Allegations of the Use of Chemical Weapons in the Syrian Arab Republic (A/68/663-S/2013/735, dated 13 December 2013). Available at: https://unoda-web.s3.amazonaws.com/wpcontent/uploads/2013/12/report.pdf

14 Contingency operations in the Syrian Arab Republic have included an OPCW-United Nations Joint Mission to remove and destroy chemical weapons that ran from 16 October 2013 to 30 September 2014 (https://opcw.unmissions.org/), Fact-Finding Missions (reports are available at: www.opcw.org/special-sections/syria/fact-finding-mission-reports/) and a Declarations Assessment Team (see "Report on the work of the Declaration Assessment Team", EC-85/DG.25, dated 4 July 2017). For further information on OPCW activities in the Syrian Arab Republic, see: www.opcw.org/special sections/syria/

investigations, analysis, and fact-finding, with collection and evaluation of oral, material, and digital evidence of the use of chemical agents. The unique and non-routine situations in which these operations have taken place are highly insightful for the consideration of new technologies with the potential to enhance capabilities available to inspectors.[16] Additionally, assistance and protection missions can also be called.[17]

5.3 Ms Katarina Grolmusova (Analytical Chemist, OPCW Inspectorate) described the differences between routine inspections and contingency operations involving OPCW inspectors. Using examples from the FFM, she highlighted technological needs and capabilities, as well as the challenges faced by inspectors during contingency operations, emphasising that these missions require field experienced specialists who are able to operate in unpredictable and dynamic environments, where improvised problem solving is often required.

5.4 Challenges in conducting non-routine missions have many dimensions, including non-technical issues that can impact the capabilities of a mission team. These can include customs and transportation regulations (especially regarding dangerous goods) that can delay arrival of or prohibit access to certain equipment, and short-notice deployment. Once inspectors are on the ground, they may have time limited access to investigation sites, find themselves working under unfavourable environmental conditions and collected samples may have low purity and/or impurities that interfere with analytical methods. Chain-of-custody and properly documenting evidence is required from the point of collecting/receiving a sample through its handling, transportation, storage and analysis (and beyond); requiring careful attention under potentially stressful conditions. Collected evidence often includes videos, photos and witness statements, which must also be authenticated, requiring expertise beyond chemical analysis. Finally, on return from a mission, inspectors may also be under time pressure to produce a mission report.

5.5 In the subsequent discussion, the following points were raised:

(a) Ms Grolmusova's presentation was highly appreciated by the workshop participants as it put into perspective many of the factors that will impact the evaluation and use of any technology in the field. Having experienced inspectors participate in technology review workshops such as this one, provides crucial insights on needs and challenges under field conditions. Practical advice on science and technology requires that operational staff from the Secretariat be engaged in the review process.

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15 Removal of chemical weapon precursors from Libya in 2016, see: www.opcw.org/news/article/libyas-remaining-chemical-weapon-precursors-arrive-safely-and-securely-at-german-facility-for-destruction/

16 (a) R. Trapp, Lessons Learned from the OPCW Mission in Syria, dated 16 December 2015, available at: www.opcw.org/fileadmin/OPCW/PDF/Lessons_learned_from_the_OPCW_Mission_in_Syria.pdf
(b) The Secretary-General's Mechanism for Investigation of Alleged Use of Chemical, Bacteriological (Biological) or Toxin Weapons: A lessons-learned exercise for the United Nations Mission in the Syrian Arab Republic (2015). Available at: https://www.un.org/disarmament/publications/more/syrian-ll-report

17 "Establishment of a Rapid Response Assistance Team" (S/1381/2016, dated 10 May 2016). Available at: www.opcw.org/fileadmin/OPCW/S_series/2016/en/s-1381-2016_e_.pdf

(b) There are many places where enabling technologies might provide value to inspectors, however the adoption of any new technology must consider the operational requirements and practical issues that might rise in the field; for example: power sources required for use, availability of consumables, set up time, and transportation requirements (including shipping weight and possible shipment restrictions). Further complicating the use of data driven technologies are potential restrictions on data transmission and the need for accurate and precise record keeping with regard to chain of custody.

(c) Useful on-site analysis tools were suggested to be those that provide preliminary detection (indicative tests), which can help to guide where to collect samples that can be sent for more robust off-site analysis. Examples of such tools that are currently available to inspectors include CALID paper (a colorimetric test)[18] and hand-held detectors[19] such as the LCD 3.3.[20]

Subitem 5(b): Aerial platforms for reconnaissance, sample planning and basic detection

5.6 Mr Guy Valente (Senior Project Officer, OPCW Assistance and Protection Branch, APB) discussed applications for unmanned aerial vehicles (UAVs) in support of chemical emergency response; with specific emphasis on area reconnaissance, scene documentation, live entry support and basic detection. These applications serve as solutions for States Parties seeking to develop a chemical forensics and evidence management (CHEMFORM) capability, in alignment with the CHEMFORM best practices initiative currently in development within the APB.[21] The CHEMFORM initiative will produce recommended best practices for responders who detect, document and take samples in contaminated environments; with a view towards establishing internationally validated classification and training materials on best practices.

5.7 In the subsequent discussion, the following points were raised:

(a) The CHEMFORM initiative is highly relevant to the work that will be undertaken by the SAB's TWG on Investigative Science and Technology.[22] In this regard the SAB would benefit from updates on the initiative as it moves forward. Members of the TWG could usefully attend the next planning and

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18 Liquid Chemical Weapon Agent Detection Papers CALID-3 (Oritest), for more information see: http://www.oritest.cz/en/products/detection/liquid-cwa-detection-papers-calid-3/

19 Testing of hand-held detectors for chemical warfare agents; A.-B. Gerber; *SPIEZ LABORATORY Annual Report 2015*, 38 – 39. Available at: https://www.labor-spiez.ch/pdf/en/dok/jab/88_003_e_laborspiez_jahresbericht_2015_web.pdf

20 For more information, see: https://www.smithsdetection.com/index.php?option=com_k2&view=item&id=86:lcd-3-3&Itemid=1421#.WVr884jyg2w

21 See paragraphs 12.6 - 12.7 of "Report of the Scientific Advisory Board at its Twenty-Fifth Session" (SAB-25/1*, dated 31 March 2017), available at: www.opcw.org/fileadmin/OPCW/SAB/en/sab2501_e_.pdf

22 See paragraphs 12.3 - 12.5 and Annex 2 of "Report of the Scientific Advisory Board at its Twenty-Fifth Session" (SAB-25/1*, dated 31 March 2017), available at: www.opcw.org/fileadmin/OPCW/SAB/en/sab2501_e_.pdf

coordination meeting of CHEMFORM stakeholders that is being planned for later this year. Input to CHEMFORM from the new TWG and the SAB could assist in ensuring that best practices in development for national chemical response teams are scientifically sound.

(b) UAV technologies with an imaging capability can be used to verify and record information to help prove chain of custody.

(c) Linking detection information to a UAVs global positioning system (GPS) was identified as a desirable feature; this capability could allow chemical presence and contamination to be indicated on maps and geospatial images.

(d) The momentum currently established in the Secretariat regarding 'retail off the shelf' UAV applications would benefit from expansion to the evaluation of more suitable sensing and detection capabilities. Such advances have clear value, for the Secretariat as well as States Parties seeking cost effective and readily accessible technology solutions for managing chemical threats.

6. AGENDA ITEM SIX – Recognising biochemical change: *If plants could talk*

6.1 Professor Vladimir Zeitsev moderated the first of three sessions focused on the recognition of biochemical change. The session concentrated on the concept of "if plants could talk" with a view toward reviewing technologies that have the potential to recognise phenotypic changes that diagnose plant health[23] (which could include recognition of exposure to toxic chemicals).

Subitem 6(a): Remote sensing of terrestrial ecosystems

6.2 Dr Greg McCarty (USDA-ARS[24] Hydrology & Remote Sensing Laboratory, United States of America, and a member of the workshop organising committee) provided the introductory material that follows in paragraphs 6.2(a), (b) and (c), covering the capabilities that have been developed for the sensing of terrestrial ecosystems.

(a) Advances in space-based sensor technologies are now capable of producing datasets with high spectral, spatial, and temporal resolution, overcoming the trade-offs between these domains of resolution that older technologies required. The older systems allowed data to be acquired at high spectral resolution but would be limited to low spatial and temporal resolution; this limited the ability to acquire detailed phenology of an ecosystem and to resolve changes in leaf biochemistry in both space and time. Mature satellite systems such as those provided by the United States of America's Landsat programme[25] are now being linked by cross-calibration to the European Union's Sentinel programme[26] to provide a validated image dataset with

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23 For example: Using Deep Learning for image-based plant disease detection; S. P. Mohant, D. P. Hughes, M. Salathé; *Front. Plant Sci.*, 2016, *7*:*1419*. DOI: 10.3389/fpls.2016.01419.

24 United States Department of Agriculture – Agriculture Research Service (USDA-ARS), https://www.ars.usda.gov/

25 For more information see: https://landsat.usgs.gov/about-landsat

26 For more information see: https://sentinel.esa.int/web/sentinel/home

approximately 3-day return frequency. The Landsat programme has built a data record that spans more than 40 years with traceable continuity between generations of sensors used within the programme which is critical for detecting long term trends within the Earth's biosphere. Continuity and enhancements in the data record by linking multiple satellite programmes will add great power to trend analysis. Spectral enhancements include the advent of hyperspectral sensors that provide full spectral information for each pixel of an image.[27]

(b) Another recent development has been the deployment of miniature satellites (CubeSats) that are less expensive to build and launch, with commercial ventures deploying large swarms of CubeSats that can acquire high resolution and high frequency data.[28] These advances will better enable data intensive technologies such as precision agriculture. Detecting phenological changes in crops in fields requires availability of data collected at high spatial and temporal frequency, with additional detection of nutrient status requiring high spectral resolution.

(c) The torrent of data that advanced Earth monitoring systems are providing requires advances in data management and processing to use such data to its full potential. Cloud computing services are vital in this effort; Google Earth Engine (GEE)[29] is an excellent example of this rapid advance. Within GEE, various earth monitoring datasets in a consistent geospatial format are available in a multi-petabyte catalogue. Development and implementation of user derived algorithms occur within the GEE environment and algorithm output is computed in real time using cloud based processors. This combination of readily assessable satellite image catalogues and high throughput computing power via cloud services promises to revolutionise our ability to monitor and understand ecological processes on various scales and to detect important trends within the Earth's biosphere.

Subitem 6(b): Technologies being adopted for precision agriculture and their potential applications

6.3 Dr Ricardo Inamasu (Embrapa[30] Labex, Brazil) provided an overview of sensor systems that are currently used for precision agriculture (farming) applications.[31]

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27 For background on the type of information that can be obtained through hyperspectral imaging of vegetation (including biochemical information), see: *Hyperspectral Remote Sensing of Vegetation*; P. S. Thenkabail, J. G. Lyon; A. Huete (eds); CRC Press, 2011, ISBN 9781439845370.

28 (a) Thinking inside the box; E. Hand; *Science*, 2015, *348(6231)*, 176 - 177. DOI: 10.1126/science.348.6231.176. (b) Startup liftoff; E. Hand; *Science*, 2015, *348(6231)*, 172 - 177. DOI: 10.1126/science.348.6231.172. (c) *Achieving science with CubeSats: thinking inside the box*, National Academies of Science, Engineering, and Medicine; National Academies Press; Washington DC, USA; 2016, ISBN: 13: 978-0-309-44263-3. DOI: 10.17226/23503.

29 Google Earth Engine (GEE). More information is available at: https://earthengine.google.com/

30 Brazilian Agricultural Research Corporation, https://www.embrapa.br/en/international

31 (a) Twenty five years of remote sensing in precision agriculture: key advances and remaining knowledge gaps; D. J. Mulla; *Biosystems Engineering*, 2013, 114(4), 358 – 371. DOI: 10.1016/j.biosystemseng.2012.08.009. (b) *Precision Agriculture Technology for Crop Farming*, Q. Zhang, 2015, CRC Press, ISBN 9781482251074.

Precision farming is the management of crops that takes into account spatial variability with the aim to increase economic return and reduce adverse effects on the environment. This process is reliant on automation and data analysis. In this context, automation can be thought of as “a system in which operational processes are controlled and executed through mechanical, electronic or computational devices that multiply the capacity of human labour.” The benefits provided by precision farming include improved crop yields and greater sustainability in farm management. Viable adoption of precision agriculture in large farms, demands sophisticated equipment and sensing systems. Dr Inamasu described this equipment, how it is deployed, and the (bio)chemical information it can provide.

6.4 In the subsequent discussion, the following points were raised:

(a) The use of hyperspectral imaging and analysis of the appropriate wavelengths of light are key aspects of the use of plants as sensors of chemical change.

(b) Satellite imagery (in particular hyperspectral and non-visible wavelength imagery) that can identify sick and healthy vegetation may have value in chemical investigations. Areas of a field in which “sick vegetation” can be observed might indicate the release of a chemical. Comparison of images showing such features with previously taken images, could help identify the time and date of an incident (assuming that sufficient collected image data and other relevant information are available).

(c) Many parameters can be monitored to determine plant health, including moisture levels, leaf and organ morphology, and photosensitive pigments. Even the adsorption of chemicals into a plant can produce a detectable change. Understanding and recognising change from overall plant characteristics requires the use of artificial intelligence (AI) based data analytics.

(d) Much data on crop plant health have been collected through agricultural activities; however such data have economic value, may be proprietary, and are often not shared across agricultural enterprises/farms. As such, the data may not be accessible as part of a monitoring effort aimed at identifying potential toxic chemical exposure in areas where a toxic chemical release is suspected.

Subitem 6(c): Optical sensors for the detection of biophysical and biochemical changes of plants: case studies from plant-pathogen interactions

6.5 Mr Matheus Kuska (University of Bonn, Germany) reviewed the use of optical sensors for detecting biophysical and biochemical changes in plants. The detection and identification of plant diseases is a fundamental task in sustainable crop production. An accurate estimate of disease incidence, disease severity and negative effects on yield quality and quantity is important for crop production, horticulture, plant breeding and basic and applied plant research. In this regard, remote and proximal sensing techniques have demonstrated a high potential for detecting disease and monitoring crop stands for infected plant areas. The most promising methods include thermography, chlorophyll fluorescence, and hyperspectral sensing. The variety of available sensor systems can provide high-resolution imagery for crop stands or single plant organs, which can permit early detection and identification of plant diseases.[32] Hyperspectral imaging, in particular, of diseased plants offers insight into processes during pathogenesis. Fungal leaf pathogens can influence both structural characteristics and the chemistry within the leaf, which in turn is reflected in the optical properties of the plant. The combination of hyperspectral imaging and data analysis routines makes early detection, identification and quantification of a range of plant diseases possible.[33]

6.6 In the subsequent discussion, the following points were raised:

(a) To fully utilise the potential of plant disease recognition with optical sensors and complex high-dimensional complex data analysis, expertise that includes plant pathology, engineering, and informatics is required. Ideally, optical sensing data can be coupled with other analysis methods (eNose technologies for example) and data streams to identify a known state of plant health that would dictate any necessary action to be taken. Examples of wearable smart devices modified for use in localised plant imaging applications have also been reported,[34] and therefore handheld means of imaging plants for signs of ill health are possible.

(b) Observable physiological and phenotypic characteristics of plants could be potentially related to molecular biological mechanisms and markers (especially using OMICS methods). Generating and understanding the data sets for imaging tools to be able to recognise characteristics and correlate to molecular effects requires building up and validating data sets.

(c) Given the wealth of information that can be inferred from observing plants (including their interaction with chemicals), it can be said that "plants can talk", but we need to learn their language. In this regard, Mr Kuska indicated

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32 (a) Hyperspectral imaging for small-scale analysis of symptoms caused by different sugar beet diseases; A. K. Mahlein, U. Steiner, C. Hillnhütter, H. W. Dehne, E. C. Oerke; *Plant Methods;* 2012, *8:3*, DOI: 10.1186/1746-4811-8-3. (b) Spectral patterns reveal early resistance reactions of barley against Blumeria Graminis; F. S. Hordei; M. T. Kuska, A. Brugger, S. Thomas, M. Wahabzada, K. Kersting, E-C. Oerke, U. Steiner, A-K. Mahlein; *Phytopathology;* 2017; DOI: 10.1094/PHYTO-04-17-0128-R. (c) Hyperspectral imaging reveals the effect of sugar beet quantitative trait loci on Cercospora leaf spot resistance; M. Leucker, M. Wahabzada, K. Kersting, M. Peter, W. Beyer, U. Steiner, A-K. Mahlein, E-C. Oerke; *Functional Plant Biology*; 2017, *44*, 1 – 9. DOI: 10.1071/FP16121.

33 (a) Early detection and classification of plant diseases with Support Vector Machines based on hyperspectral reflectance; T. Rumpf, A.-K. Mahlein, U. Steiner, E.-C. Oerke, H.-W. Dehne, L. Plümer; *Computers and Electronics in Agriculture;* 2010, *74,* 91 - 99. (b) A review of advanced machine learning methods for the detection of biotic stress in precision crop protection; J. Behmann, A. K. Mahlein, T. Rumpf, C. Römer, L. Plümer; *Precision Agriculture;* 2015; *16;* 239 - 260. DOI: 10.1007/s11119-014-9372-7. (c) Metro maps of plant disease dynamics—automated mining of differences using hyperspectral images; M. Wahabzada, A-K. Mahlein, C. Bauckhage, U. Steiner, E-C. Oerke, K. Kersting; *PLOS One;* 2015. DOI: 10.1371/journal.pone.0116902. (d) Generation and application of hyperspectral 3d plant models; J. Behmann, A-K. Mahlein, S. Paulus, H. Kuhlmann, E-C. Oerke, L. Plümer; *Computer Vision*; 2015, *8928*, 117– 130. DOI: 10.1007/978-3-319-16220-1_9. (e) Plant Phenotyping using Probabilistic Topic Models: Uncovering the Hyperspectral Language of Plants; M. Wahabzada, A-K. Mahlein, C. Bauckhage, U. Steiner, E-C. Oerke, K. Kersting; *Scientific Reports;* 2016, *6.* DOI: 10.1038/srep22482.

34 Quantification of plant chlorophyll content using Google Glass; B. Cortazar, H. C. Koydemir, D. Tseng, S. Feng, A. Ozcan; *Lab on a Chip*; 2015, *7*,708-1716 . DOI: 10.1039/C4LC01279H.

that there are efforts to develop hyperspectral libraries to share data with non-experts.

7. AGENDA ITEM SEVEN – Recognising biochemical change: *large scale environmental monitoring*

7.1 Professor Ahmed Saeed moderated the second session which focused on the recognition of biochemical change, using satellites and dispersion models to monitor chemical release.

Subitem 7(a): On-site data fusion – satellites and dispersion models: The 2016 Al-Mishraq sulphur plant fire

7.2 Dr Oscar Björnham (Swedish Defense Research Agency, FOI[35]) presented his analysis of the fire at the sulphur production site Al-Mishraq which had been started on 20 October 2016 by Daesh (Islamic State) during the battle of Mosul.[36] A huge plume of toxic sulphur dioxide (SO_2) and hydrogen sulphide (H_2S) was produced, causing casualties, with the intensity of the SO_2 release reaching levels of minor volcanic eruptions that could be observed by several satellites.[37] 2D-data from the MetOp-A and MetOp-B,[38] Aura,[39] Suomi,[40] and Meteosat-10[41] satellites provided information on the dynamic concentration fields during the period. By incorporating a long-range dispersion model, a source term that gave rise to the best reproduction of the concentration fields over the Middle East was found. The dispersion model was therefore able to estimate the dynamic 3D-concentration field. The ground-level concentrations predicted by the simulation were compared with observations from the Turkish National Air Quality Monitoring Network.[42] Finally, the simulation data provided, using a probit analysis to estimate the human health risk area at ground level, was compared to reported cases of exposure that had required urgent medical treatment. The study demonstrated the potential for combining satellite measurements with numerical models to acquire new insight into ongoing events, both by increasing the accuracy of already available data and by providing new information.

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35 Swedish Defence Research Agency (FOI), https://www.foi.se/en.html

36 The 2016 Al-Mishraq sulphur plant fire: source and risk estimation; O. Bjornham, H. Grahn, P. von Schoenberg, B. Liljedahl, A. Waleij, N. Brännström; 2017, *arXiv:*1611.03837v4 [physics.ao-ph], https://arxiv.org/abs/1611.03837

37 Toxic gas plume spreading across Iraq; M. Gunther; *Chemistry World;* 1 November 2016, https://www.chemistryworld.com/news/toxic-gas-plume-spreading-across-iraq/1017623.article

38 Meteorological Operational Satellite A and B (MetOp-A and MetOp-B). More information is available at: https://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/index.html

39 Aura. More information is available at: https://aura.gsfc.nasa.gov/

40 Suomi-NPP. More information is available at: https://jointmission.gsfc.nasa.gov/suomi.html

41 Meteosat-10. More information is available at: https://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Meteosat/index.html

42 Republic of Turkey Ministry of Environment and Urbanization, Air Quality Monitoring Stations Website. Available at: http://www.havaizleme.gov.tr/Default.ltr.aspx

7.3 In the subsequent discussion, the following points were raised:

(a) The available satellite data allowed analysis of SO_2, but not other chemical species. It was suggested that analysis of particulate matter to build the dispersion model might also be explored, the premise being that the dispersion of particulates would have correlation to a broader set of harmful chemical species emitted from the fire (and be of relevance to the release of toxic chemicals by pyrotechnic means, one of the dispersal mechanisms of some chemical weapons).

(b) Validation of the models is necessary for making them generally applicable and useful predictively. The current results demonstrate the value of them; further work might focus on looking for ways to make the analysis quick and accurate enough to support risk determination and emergency response (the current dataset took several weeks to develop).

8. AGENDA ITEM EIGHT – Recognising biochemical change: *chemical sensing*

8.1 Dr Veronica Borrett moderated the final session focused on the recognition of biochemical change, which considered sensor and eNose technologies.

Subitem 8(a): Targeted catalytic degradation of organophosphates: pursuing sensors

8.2 Professor Elisa Orth (Federal University of Parana, Brazil) described the potential use of catalysts for degrading organophosphates (OPs) as sensors for these types of chemicals. OPs represent a chemical health concern with pesticides and nerve agents both being derived from chemicals falling in this general class. One approach for both degrading and sensing OP compounds is the use of carbonaceous-based materials, such as graphene and carbon nanotubes (NTC) which can be functionalised with multiple catalytic groups to provide enhanced synergistic effects. Professor Orth described her work in targeted functionalisation of graphene oxide and NTCs, combined with metallic nanoparticles to obtain nanocatalysts for OP degradation.[43] These nanocatalysts can be prepared as a solid or a thin film, with the latter having the advantage of facile recovery and deposition over several substrates. Additionally, these thin films show potential as a surface enhanced Raman Spectroscopy (SERS) sensor for OP degradation. Professor Orth's nanocatalysts have promoted up to 107-fold enhancement in reaction rate for the degradation, accelerating a reaction that would take over three million years to nearly 30 days. The catalysts have been prepared as solids with magnetic properties (using NTCs) that allow recovery with a magnet, and as films on sustainable materials such as rice husk.[44] Professor Orth also

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43 (a) Targeted thiolation of graphene oxide and its utilization as precursor for graphene/silver nanoparticles composites; E. S. Orth, J. E. S. Fonsaca, S. H. Domingues, H. Mehl, M. M. Oliveira, A. J. G. Zarbin; *Carbon*; 2013, *61*, 543 - 550. DOI: 10.1016/j.carbon.2013.05.032. (b) Functionalized graphene oxide as a nanocatalyst in dephosphorylation reactions: pursuing artificial enzymes; E. S. Orth, J. E. S. Fonsaca, T. G. Almeida, S. H. Domingues, J. G. L. Ferreira, A. J. G. Zarbin; *Chem. Commun.;* 2014, 50, 9891 - 9894. DOI: 10.1039/C4CC03262D.

44 Degrading pesticides with waste product: Imidazole-functionalized rice husk catalyst for organophosphate detoxification; E. S. Orth, J. G. L. Ferreira*; Journal of the Brazilian Chemical Society*, 2017, *28*, 1760-1767. DOI: 10.21577/0103-5053.20170027.

described methods to construct low cost colorimeters that can detect OPs compounds and monitor their catalytic degradation.[45]

8.3 In the subsequent discussion, the following points were raised:

(a) Fundamental chemical research on catalytic means of destroying nerve agents and other toxic chemicals is important as it may offer new solutions for the destruction of chemicals under resource limited settings and/or assist mobile destruction technologies.

(b) The low cost colorimeters have been successfully used in student laboratory projects, and can also be used in agricultural fields to identify high pesticide levels on harvested fruit. The catalysts can also be regenerated, providing for multi-use sensors. With appropriate modifications, the system could have potential application as a point-of-care device for detection of OP pesticides/nerve agent simulants in a resource limited setting. This could be usefully evaluated in a training exercise.

Subitem 8(b): Multisensor systems (eNose) for toxic gases detection and biomedical applications

8.4 Professor Cristhian Manuel Durán Acevedo (Universidad De Pamplona, Colombia) described eNose technologies and their applications in gas sensing (with a focus on explosive and toxic gases in mine shafts)[46] and medical diagnosis.[47] He described how monitoring airborne chemicals in large facilities can be carried out using the combination of electronic nose (eNose) technologies with wireless communication systems, noting that these systems are advantageous due to low installation and maintenance costs compared to conventional wiring and chemical monitoring instrumentation.[48]

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45 Introdução à físico-química orgânica utilizando um colorímetro artesanal - uma prática interdisciplinary; E. S. Orth, V. B. Silva; *Quím. Nova;* 2017, *40,* 238 - 245. DOI: 10.21577/0100-4042.20160178.

46 (a) Sistema de olfato electrónico para la detección de compuestos volátiles; A.C. Durán, J.C. Rodríguez; *RevicolodetecnodeAvan;* 2008, *12*, 20 – 26. (b) Detección y control de atmósferas explosivas enminas subterráneas de carbon usando programación e structurada; *D. R. Echeverri, S. H. R. Cano, J. A. J. Builes*; *Revi. Educ.en Inge,;* 2012, *7*, 710 – 721. (c) Gas explosion venting: comparison of square and circular vents; B. Fakundu, G. Andrews, H. Phylaktou; *Chem. Engi. Tran.;* 2014, *36*, 163 - 168. DOI: 10.3303/CET1436028.

47 (a) Nanomaterial-based sensors for detection of disease by volatile organic compounds; Y.Y. Broza, H. Haick; *Nanomedicine*; 2013, 8, 785 - 806. DOI: 10.2217/nnm.13.64. (b) Analysis of exhaled breath for disease detection; A. Amann, W. Miekisch, J. Schubert, B. Buszewski, T. Ligor, T. Jezierski, J. Pleil, T. Risby; *Annual Review of Analytical Chemistry*; 2014, 7, 455 - 482.

48 (a) Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards; P. Baronti, P. Pillai, W. V. Chook, S. Chessa, A. Gotta, Y. Hu; *Comp. Comm*.; 2007, *30*, 1655 - 1695. DOI: 10.1016/j.comcom.2006.12.020. (b) Analysis of the power consumption for wireless sensor network node based on Zigbee; S. Chen, J. Yao, Y. Wu; *Procedia Engineering;* 2012, *29*, 1994 - 1998. DOI: 10.1016/j.proeng.2012.01.250. (c) A review of wireless communications for smart grid; A. Mahmood, J. Nadeem, S. Razzaq; *Renewable and Sustainable Energy Review;* 2015, *41*, 248 - 260. DOI: 10.1016/j.rser.2014.08.036.

8.5 Early detection and diagnosis of gastric cancer has also been demonstrated using eNose devices composed of a set of nanoparticle gas sensors,[49] a sampler device and data acquisition system. A clinical study was described, where patients were evaluated by medical tests (biopsy and endoscopy) before and after using the eNose to acquire a set of alveolar breath samples.[50] Samples were collected from Gastric Cancer (GC) patients, with patients having other gastric problems (e.g. gastritis and ulcers) used as a control group. The eNose method demonstrated a classification rate of 94%. To validate the results, another set of breath measurements of GC and controls were acquired by Tenax® TA tube pre-concentrators and analysed by GC-mass spectrometry (GC/MS). The methodology promises to be a useful tool for implementation in clinical settings.

8.6 In the subsequent discussion, the following points were raised:

(a) Detection limits for eNose sensors appear to be very sensitive under certain conditions (measuring chemical species in exhaled breath); however it is the recognition of specific chemical species by the pattern of sensor responses that is their strength. How reliable the tools are for chemical recognition depends on the datasets and algorithms used in the analysis.

(b) While an eNose is capable of detecting mixtures of exhaled biomarkers, it cannot identify them, requiring training of the algorithm to recognise patterns of signal across the sensors that correlate to specific chemical species.

(c) The use of eNose systems for detecting disease from breath analysis requires clinical studies to train algorithms and build datasets that can be validated against traditional methods of diagnosis.

(d) The utility of eNose technologies has been demonstrated for detecting chemical vapours associated with volatile organic compounds,[51] waste

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49 (a) Sniffing the unique "odor print" of non-small-cell lung cancer with gold nanoparticles; O. Barash, N. Peled, F. R. Hirsch, H. Haick; *Small;* 2009, *5*, 2618 - 2624. DOI : 10.1002/smll.200900937. (b) A nanomaterial-based breath test for distinguishing gastric cancer from benign gastric conditions; Z.-Q. Xu, Y. Y. Broza, R. Ionescu, U. Tisch, L. Ding, H. Liu, Q. Song, Y.-Y. Pan, F.-X. Xiong, K.-S. Gu, G.-P. Sun, Z.-D. Chen, M. Leja, H. Haick; *BJC*; 2013, *108*, 941-950. DOI : 10.1038/bjc.2013.44.

50 Ultrapure Organically Modified Gold Nanoparticles for Breath Analysis; T. G. Welearegay, O. E. Gualdrón, A. L. Jaimes, J. M. Cáceres, G. Pugliese, U. Cindemir, C. M. Durán, L. Österlund, R. Ionescu; *Procedia Engineering*; 2016, *168*, 133 - 136. DOI: 10.1016/j.proeng.2016.11.176.

51 Currently commercially available chemical sensors employed for detection of volatile organic compounds in outdoor and indoor air; B. Szulczyński, J. Gębicki; *Environments*, 2017, *4(1)*, 21 - 35. DOI: 10.3390/environments4010021.

management plants[52] and food quality[53] (in some instances combined with an "eTongue" [54]).

9. AGENDA ITEM NINE – Mobile and wearable technologies and point-of-care devices

9.1 Dr Evandro de Souza Nogueria moderated a session focused on wearable and point-of-care devices for chemical sensing.

Subitem 9(a): Flexible, foldable, and wearable paper-based electronics and electrochemical devices

9.2 Professor Murilo Santhiago (Brazilian Nanotechnology National Laboratory LNNano[55]) described his work on paper-based electronic devices.[56,57,58] Cellulose based materials can be thin, flexible, foldable, and biocompatible, making them suitable substrates for the fabrication of a variety of electronic and electrochemical devices. Professor Santhiago described the fabrication, characterisation, applications and challenges of flexible polypyrrole, carbon-based[59] and printed carbon black conductive nanostructures for high-performance electronic, electrochemical, and wearable devices. His laboratory developed the fabrication of electronic interconnects through the substrate, allowing the construction of three dimensional functional electronic devices.[60,61] Through doping/dedoping

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52 Improving recognition of odors in a waste management plant by using electronic noses with different technologies, gas chromatography–mass spectrometry/olfactometry and dynamic olfactometry; P. Giungato, G. Gennaro, P. Barbieri, S. Briguglio, M. Amodio, L. Gennaro, F. Lasigna; *Journal of Cleaner Production*, 2016, *133*, 1395 – 1402. DOI: 10.1016/j.jclepro.2016.05.148.

53 Advances of electronic nose and its application in fresh foods: a review; H. Shi, M. Zhang, B. Adhikari; *Critical Reviews in Food Science and Nutrition*; 2017. DOI: 10.1080/10408398.2017.1327419.

54 Fusion of electronic nose, electronic tongue and computer vision for animal source food authentication and quality assessment – a review; A. R. Di Rosaa, F. Leonea, F. Chelib, V. Chiofaloa; *Journal of Food Engineering*, 2017, *210*, 62 – 75. DOI: 10.1016/j.jfoodeng.2017.04.024.

55 Brazilian Nanotechnology National Laboratory (LNNano), http://lnnano.cnpem.br/

56 A new approach for paper-based analytical devices with electrochemical detection based on graphite pencil electrodes; M. Santhiago, L. T. Kubota; *Sens. Actuators B Chem.;* 2013, *177*, 224 - 230. DOI: 10.1016/j.snb.2012.11.002.

57 Separation and electrochemical detection of paracetamol and 4-aminophenol in a paper-based microfluidic device; L. Y. Shiroma, M. Santhiago, A. L. Gobbi, L. T. Kubota; *Anal. Chim. Acta;* 2012, *725*; 44 - 50. DOI: 10.1016/j.aca.2012.03.011.

58 Construction and electrochemical characterization of microelectrodes for improved sensitivity in paper-based analytical devices; M. Santhiago, J. B. Wydallis, L. T. Kubota, C. S. Henry; *Anal. Chem.;* 2013, *85*, 5233 - 5239. DOI**:** 10.1021/ac400728y.

59 Direct drawing method of graphite onto paper for high-performance flexible electrochemical sensors; M. Santhiago, M. Strauss, M. P. Pereira, A. S. Chagas, C. C. B. Bufon; *ACS Appl. Mater. Interface;* 2017, *9*, 11959 – 11966. DOI: 10.1021/acsami.6b15646.

60 Three-dimensional organic conductive networks embedded in paper for flexible and foldable devices; M. Santhiago, J. Bettini, S. R. Araújo, C. C. B. Bufon, *ACS Appl. Mater. Interfaces*; 2016, *8*, 10661 -10664. DOI: 10.1021/acsami.6b02589.

61 Low cost, simple three dimensional electrochemical paper-based analytical device for determination of *p*-nitrophenol; M. Santhiago, C. S. Henry, L. T. Kubota; *Electrochimica Acta;* 2014, *130*, 771 - 777. DOI: 10.1016/j.electacta.2014.03.109.

processes, it is also possible to detect harmful chemical compounds. Carbon-based materials can be prepared using a dry transfer process of graphite onto paper that is combined with an electrochemical process to create high-performance electrochemical devices. With this approach, a low-cost and flexible carbon-based platform for the construction of reduced nicotinamide adenine dinucleotide (NADH)-based biosensors was developed.[62]

9.3 In the subsequent discussion, the following points were raised:

(a) Research into these low-cost and foldable systems is valuable for developing components with applications in fabrication of wearable sensor devices.

(b) Low cost, low weight and flexible devices are ideal if the sensor technology is to be made accessible on a large scale for use in the field.

Subitem 9(b): Wearable technology for chem/bio: existing and emerging capabilities

9.4 Dr Richard Ozanich (Pacific Northwest National Laboratory, United States of America[63]) reviewed existing and emerging wearable sensors for chemical and biological threat agents, identifying the essential enabling developments, expected capabilities, and key challenges in the field. He described wearables that can be inward looking (self-monitoring) or outward looking (environmental) sensors.

9.5 Enablers for wearable technologies for chemical and biological security applications include miniaturisation, sensors, nanomaterials, robust flexible electrical systems, transdermal biological fluid extraction (including sweat sensors[64] and microneedles[65]), microscale power and storage, knowledge of biomarkers for disease and/or chemical exposure, and communication capabilities. Difficulties to realise these enablers include obtaining stable and reversible (bio)chemical receptors, understanding of the relevant biomarkers in accessible body fluids (e.g. sweat), and cost. Dr Ozanich suggested that many of the desired capabilities in wearables were likely to be 10 years away.

9.6 In the subsequent discussion, the following points were raised:

(a) Wearables for sports (monitoring athletes) have driven many advances in the field, primarily for inward looking non-invasive health monitoring. It was noted that very few inward looking chemical monitors have been reported;

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62 Microfluidic paper-based devices for bioanalytical applications; M. Santhiago, E. W. Nery, G. P. Santos, L. T. Kubota; *Bioanalysis;* 2014, *6*, 89 – 106. DOI: 10.4155/bio.13.296.

63 Pacific Northwest National Laboratory (PNNL), http://www.pnnl.gov/

64 Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis; W. Gao, S. Emaminejad, H. Y. Y. Nyein, S. Challa, K. Chen, A. Peck, H. M. Fahad, H. Ota, H. Shiraki, D. Kiriya, D.-H. Lien, G. A. Brooks, R. W. Davis, A. Javey: *Nature;* 2016, *529*, 509 – 514. DOI: 10.1038/nature16521.

65 A graphene-based electrochemical device with thermoresponsive microneedles for diabetes monitoring and therapy; H. Lee, T. K. Choi, Y. B. Lee, H. R. Cho, R. Ghaffari, L. Wang, H. J. Choi, T. D. Chung, N. Lu, T. Hyeon, S. H. Choi, D.-H. Kim; *Nature Nanotechnology*; 2016, *11*, 566 – 572. DOI: 10.1038/nnano.2016.38.

however the ability to recognise abrupt changes in vital signs from non-invasive monitors, if correlated to symptoms of exposure, could be valuable and is currently possible.[66]

(b) A wearable self-monitoring cholinesterase activity device would be of relevance in identifying nerve agent exposure. While point-of-care devices are available for other applications, continuous and real-time cholinesterase monitoring is currently a challenge.[67]

(c) For chemical detection, many outward looking wearables have been reported, including passive materials that absorb chemicals (which are extracted and analysed)[68] and colorimetric toxic gas sensor arrays;[69] the latter includes examples capable of detecting explosives[70] and OP compounds.[71] Enzymatic indicators for airborne chemical agents such as sulphur mustard might also have applications as wearable early warning indicators.[72] Reliability, sensitivity and false positive/negative rates for such devices would need to be characterised to evaluate their suitability for field use.

(d) Common air pollutants (and particulates[73]) can be monitored with currently available sensors; however environmental background levels are highly variable with noise levels that can mask low concentrations of airborne toxic chemicals.

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66 For example the monitoring of oxygen indices: The First-in-Man “Si Se Puede” study for the use of micro-oxygen sensors (MOXYs) to determine dynamic relative oxygen indices in the feet of patients with limb-threatening ischemia during endovascular therapy; M. F. Montero-Baker, K. Y. Au-Yeung, N. A. Wisniewski, S. Gamsey, L. Morelli-Alvarez, J. L. Mills Sr, M. Campos, K. L. Helton; *J. Vasc. Surg.;* 2015, *61*, 1501 - 1510. DOI: 10.1016/j.jvs.2014.12.060.

67 On-site analysis of acetylcholinesterase and butyrylcholinesterase activity with the ChE check mobile test kit - Determination of reference values and their relevance for diagnosis of exposure to organophosphorus compounds; F. Worek, M. Schilh, K. Neumaier, N. Aurbek, T. Wille, H. Thiermanna, K. Kehe; *Toxicology Letters*, 2016, *249*, 22 – 28. DOI: 10.1016/j.toxlet.2016.03.007.

68 Silicone wristbands as personal passive samplers; S. G. O’Connell, L. D. Kincl, K. A. Anderson; *Environ Sci Technol*.; *2014*, *48*, 3327 – 3335. DOI: 10.1021/es405022f.

69 (a) A colorimetric sensor array for identification of toxic gases below permissible exposure limits; L. Feng, C. J. Musto, J. W. Kemling, S. H. Lim, K. S. Suslicka; *Chem. Commun. (Camb)*; 2010, *46*, 2037 – 2039. DOI: 10.1039/b926848k. (b) Two-dimensional atomic-layered alloy junctions for high-performance wearable chemical sensor; B. Cho, A. R. Kim, D. J. Kim, H-S. Chung, S. Y. Choi, J-D. Kwon, Sang, W. Park, Y. Kim, B. H. Lee, K. H. Lee, D-H. Kim, J. Nam, M. G. Hahm; *ACS Appl. Mater. Interfaces*; 2016, *8*; 19635 – 19642. DOI: 10.1021/acsami.6b05943.

70 An optoelectronic nose for identification of explosives; K. S. Suslick, J. R. Askim, Z. Li, M. K. LaGasse, J. M. Rankina; *Citation. Chem. Sci.;* 2016, *7*, 199 - 206. DOI: 10.1039/C5SC02632F.

71 Discrimination of nerve gases mimics and other organophosphorous derivatives in gas phase using a colorimetric probe array; K. Chulvi, P. Gaviña, A. M. Costero, S. Gil, M. Parra, R. Gotor, S Royo, R. Martínez-Máñez, F. Sancenón, J. L. Vivancos; *Chem Commun (Camb);* 2012, *48,* 10105-10107. DOI: 10.1039/c2cc34662a.

72 Enzyme-based test strips for visual or photographic detection and quantitation of gaseous sulfur mustard; S. Bidmanova, M,-S. Steiner, M. Stepan, K. Vymazalova, M. A. Gruber, A. Duerkop, J. Damborsky, Z. Prokop, O. S. Wolfbeis; *Anal. Chem.;* 2016, *88,* 6044–6049. DOI: 10.1021/acs.analchem.6b01272.

73 Design of a light-scattering particle sensor for citizen science air quality monitoring with smartphones: tradeoffs and experiences; M. Budde, M. Köpke, M. Beigl; *ProScience;* 2016, *3*, 13 - 20. DOI: 10.14644/dust.2016.003.

(e) Development of fieldable inward looking chemical sensors faces a number of challenges; these include materials, energy supply, analysis, communication, acquisition, data processing, and security.[74] In regard to energy, strategies to power mobile devices using energy created by walking have been demonstrated.[75]

(f) Wearable detection devices, even with simple colorimetric tests could serve as valuable early detection warning systems; the ability to have skin patches or to incorporate the device into personal protective equipment offers potential advantages. Colorimetric indicators that can detect vapours rather than requiring direct contact with a liquid agent are ideal for this application. These indicators would be complementary to the detection tools currently used by OPCW inspectors.

10. AGENDA ITEM TEN – Digital Health

10.1 Professor Ponnadurai Ramasami moderated a session focused on devices that can monitor health information with real time feedback.

Subitem 10(a): Digital health: what you can learn from your smartwatch

10.2 Dr Xiao Li (Stanford University, United States of America) described the new wave of wearable sensors that enable frequent and continuous measurements of body functions (physiology), including heart rate, skin temperature, blood oxygen levels, and physical activity. She reviewed an investigation of the ability of wearable sensors to follow physiological changes that occur over the course of a day, during illness and other activities.[76] Data from these sensors revealed personalised differences in daily patterns of activities, and showed striking changes in response to particular environments such as airline flights. Blood oxygen levels decreased during high-altitude flights, and this decrease was associated with fatigue. By combining sensor information with frequent medical measurements, two important health-related observations were made. First, wearable sensors were useful in identifying the onset of inflammation and what was later diagnosed as Lyme disease. From these observations, a computational algorithm for personalised disease detection using sensor data was developed. Second, it was found that wearable sensors can reveal physiological differences between insulin-sensitive and insulin-resistant individuals, raising the possibility that these sensors could help detect risk for Type 2 diabetes. Overall, the results indicate that the information provided by wearable sensors is

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74 Wearable chemical sensors: present challenges and future prospects; A. J. Bandodkar, I. Jeerapan, J. Wang; *ACS Sens;* 2016, *1*, 464–482. 2016, *7*, 199 - 206. DOI: 10.1021/acssensors.6b00250.

75 Sustainably powering wearable electronics solely by biomechanical energy; J. Wang, S. Li, F. Yi, Y. Zi, J. Lin, X. Wang, Y. Xu, Z. L. Wang; *Nature Communications*, 2016, *7:12744*. DOI: 10.1038/ncomms12744.

76 Digital health: tracking physiomes and activity using wearable biosensors reveals useful health-related information; X. Li, J. Dunn, D. Salins, G. Zhou, W. Zhou, M. S. Rose, D. Perelman, E. Colbert, R. Runge, S. Rego, R. Sonecha, S. Datta, T. McLaughlin, M. P. Snyder; *PLoS Biol.*; 2017, *15(1)*: e2001402. DOI: 10.1371/journal.pbio.2001402.

physiologically meaningful and actionable. Wearable sensors have the potential to play an important role in monitoring health status.

Subitem 10(b): Understanding smart data collection vs Big Data collection and how to focus artificial intelligence (AI) analysis

10.3 Mr George Harris (Founder and Chief Technology Officer, Basil Leaf Technologies, United States of America[77]) discussed the use of Smart Data in making health diagnosis. Big Data and Active Machine Learning, with its large, voluminous data sets and hundreds, or even thousands, of servers working to provide analysis can be impractical for delivering solutions to locations that are remote, have infrastructure problems, or are insecure. Smart Data is a methodology that uses AI systems to create solution sets that can be packaged into smaller, transportable systems (such as smart phones, tablets or watches) that would not have access to uplink feeds during use, but can still provide accurate data analysis at the point of collection. Data and analyses can then be shared at a later time, as the user's environment changes.

10.4 Basil Leaf Technologies developed DxTER™ as a solution to the Qualcomm Tricorder XPRIZE.[78,79,80] DxTER™ embodied the use of the tools and techniques described in the previous paragraph to create a medical device. The device was required to be usable by a layperson in a remote/disconnected setting to diagnose, with at least a 70% accuracy rate, if they do or do not have any of one of 13 diseases and conditions, while monitoring five vital signs and maintaining a high user-friendly interface and experience.[81]

10.5 In the subsequent discussion of the presentations from Dr Li and Mr Harris, the following points were raised:

(a) Wearable devices that can track health related information have many potential applications in monitoring individuals working in remote and dangerous environments and/or under other stressful conditions (extended hours on airplanes for example). It is important to keep abreast of further developments in the field, to better understand practical use and clinical potential.

(b) Dr Li’s work demonstrated that it is possible to find correlations between monitored signals and the health status of an individual. While changes in the monitored health indicators may not diagnose the health condition responsible for the onset of the changes, such changes could serve as a trigger to seek medical advice.

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77 Basil Leaf Technologies, LLC, http://www.basilleaftech.com/

78 For further information see: http://tricorder.xprize.org/

79 Emergency physician in finals for Qualcomm Tricorder XPRIZE; E. Berger; *Annals of Emergency Medicine*, 2016, *67(1)*, A15 – A17. DOI, dx.doi.org/10.1016/j.annemergmed.2015.09.011

80 DxTER™ was awarded first place on 12 April 2017, http://tricorder.xprize.org/teams

81 Guidelines for the XPRIZE can be found at: http://tricorder.xprize.org/about/guidelines

(c) One area of application could be real-time health and safety monitoring in environments where workers are at risk from chemical exposure. In this respect, the technologies allow individuals to be monitored for significant changes in vital signs, rather than or in addition to, monitoring dosage of exposure over given time periods as is often the practice used to minimise worker risk in some hazardous environments.

(d) Digital health technologies have additional potential applications for first responders and those inspecting contaminated areas. Chemical test kits with mobile apps that guide users could be envisioned as a future enabling technology.

(e) In technical publications within the field, digital health technologies are seen as enabling technologies to help medical doctors make better decisions and diagnoses. For consumer use, Mr Harris suggested that about 200 disease indicators would need to be available to allow routine diagnostic use. This requires expanding molecule/phenotypic detection algorithms and ideally finding the minimum number of observations required to aid identification of a given clinical condition.

(f) A significant challenge for digital health technologies is to be as non-invasive as possible, avoiding the use of blood draw. Mr Harris also noted that placement of monitors on fingers can provide good quality vital sign data; however such placements are not user friendly for extended data collection times.

(g) The potential use of digital health technologies for clinical decision making is still in an exploratory phase. Appropriate processes for bringing these devices into clinical use, and the regulatory oversight that would govern their use, requires development.

11. AGENDA ITEM ELEVEN – Collecting data in remote and dangerous environments

11.1 Mr Cheng Tang (Vice-Chairperson of the SAB) moderated a session focused on capabilities of unmanned equipment.

Subitem 11(a): Unmanned airborne mass spectrometer (UAS-MS) for autonomous *in-situ* chemical measurements under harsh environment conditions

11.2 Dr Jorge Andrés Díaz (University of Costa Rica) reviewed his work involving the use of unmanned aerial vehicles (UAVs) for making chemical and physical measurements in the study of volcanoes. The integration of small UAVs with increasing payload capacity to carry a variety of chemical and physical sensor packages and instrument technologies is enabling the development of completely autonomous unmanned aerial systems (UAS) for *in-situ* chemical analysis that can be used under harsh environmental conditions. This development has strongly impacted the way researchers and civil authorities can explore locations that were previously unreachable, due to hazardous conditions involved in collecting real time chemical or geophysical information near the source (for example, in the assessment of eruptive volcanoes[82]). With UAS, *in-situ* and proximal remote sensing measurements of volcanic plumes are now possible, without risking human lives, and that enable the collection of *in-situ* data very close to an eruption (something that had previously not been possible). This new *in-situ* measurement and validation capability improves the monitoring of pre-eruptive and eruptive volcanic emissions in harsh environments, allowing the acquisition of data to enhance trajectory models and provide better forecasting of volcanic plume impact on nearby cities and civil aviation. If this is possible around active volcanoes, the same technology should also be capable of assessing chemical weapons release, and chemical warfare agent presence without risk to first responders, as well as providing a means to assess a potentially contaminated area without requiring personnel on the ground.

11.3 Dr Diaz described two systems: the miniGAS[83] and the miniMS. The miniGAS has a 1.2 kg payload that includes 4 chemical sensors; pressure, temperature and relative humidity sensors; GPS, onboard data storage, and video camera. Data is transmitted by telemetry in real time, generating 3D gas concentration maps of the active volcanic plumes. The miniMS has a 10 kg payload system that incorporates a miniature mass spectrometer (MS) with mass range of 1-200 amu, together with the world's smallest turbo molecular pump, embedded PC and telemetry for real time chemical analysis of the target area. Both systems have been successfully integrated into different unmanned aerial platforms and field tested, targeting *in-situ* volcanic emissions and plume analysis for calibration and validation of NASA satellite based remote sensing data from volcanoes in Costa Rica (Turrialba, Miravalles and Poas),[84] Italy (Solfatara[85] and Vulcano Island), Nicaragua (Masaya) and the United States of America (Kilauea). Dr Diaz concluded his presentation with considerations of how these systems might also be used in chemical security applications and situations.[86]

11.4 In the subsequent discussion, the following points were raised:

(a) *In-situ* measurements are critically needed to evaluate the models developed in the study of volcanic emissions, and therefore tools that allow accurate measurement to be taken in these hazardous environments are necessary.

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82 Unmanned aerial mass spectrometer systems for in-situ volcanic plume analysis; J. A. Díaz, D. Pieri, K. Wright, P. Sorensen, R. Kline-Shoder, R. Arkin, M. Fladeland, G. Bland, M. Fabrizia Buongiorno, C. Ramirez, E. Corrales, A. Alan, O. Alegria, D. Diaz, J. Linick; *J. Am. Soc. Mass Spectrom.*; 2015), *26(2)*, 292 – 304. DOI: 10.1007/s13361-014-1058-x.

83 iMet-miniGAS: Multi-gas sensor for UAV integration. More information is available at: http://www.intermetsystems.com/products/UAV-Gas-Sensor

84 (a) In situ sampling of volcanic emissions with a UAV sensorweb: progress and plans; D. Pieri, J. A. Díaz; *L.N.C.S;* 2015, *8964*. 16-27. DOI: 10.1007/978-3-319-25138-7_3. (b) Constraining the sulfur dioxide degassing flux from Turrialba volcano, Costa Rica using unmanned aerial system measurements; X. Xi, M. S. Johnson, S. Jeong, M. Fladeland, D. Pieri, J. A. Díaz, G. L. Bland; *Journal of Volcanology and Geothermal Research;* 2016, *325*, 110-118.

85 Use of multiple in situ and remote sensing instruments and techniques at Solfatera field campaign for measurements of CO_2, H_2S, and SO_2 emissions: special demonstration on unmanned aerial systems; M. Silvestri, J. A. Díaz, E. Marotta, M. Musacchio, M. F. Buongiorno, F. Sansiverom, C. Cardellini, D. Pieri, A. Carandente, L. Colini, F. Doumaz, R. Peluso, C. Spinetti; *Quaderni di Geofisica;* 2015; *Quaderni di Geofisica*, *129*, 3 – 25.

86 See also: Drones detect threats such as chemical weapons, volcanic eruptions; S. Everts, M. Davenport; *Chemical & Engineering News*; 2016, *94(9)*, 36-37.

Dr Diaz noted that his team still loses UAVs periodically, but the transmitted data are more valuable than the machine (this is also a driver to build cost effective equipment).

(b) Of relevance to non-proliferation activities with a mass spectrometer equipped UAV, Dr Diaz suggested that a system for chemical agent analysis should have similar logistical requirements to the equipment he uses: a UAV with 12 kg payload, 1 hour flight time, 3 - 5 km range, automatic take off/landing capability to allow sampling capabilities would be well suited. The mass spectrometers his research uses can make measurements in the 100-200 amu mass range, which would be able to detect sulphur mustard, nerve agents and their degradation products.

Subitem 11(b): Collection and processing of biological samples in remote and dangerous places; the environmental sample processor (ESP) as a case study

11.5 Dr Jim Birch (Monterey Bay Aquarium Research Institute, MBARI, United States of America[87]) described the use of marine unmanned systems for sample collection and processing. He noted that life on earth depends on the oceans. Food production, weather, climate, and nutrient cycling are obvious influences that impact humans, while less obvious may be the contributions of plant and microbial communities; for example 70% of the oxygen in our atmosphere, which comes from phytoplankton photosynthesis.

11.6 Despite their contribution to life on the planet, the oceans have proven problematic to study, in part because persistent access can be difficult and costly. Dr Birch described the designing, testing, and deploying of instruments by MBARI that address the issue of access. The analytical sides of these instruments are modelled after the tools and techniques derived from the biomedical diagnostics and research industries. Coupling these analytical techniques with traditional oceanographic sensors that characterise the physical, chemical and optical properties of ocean waters has led to the concept of the ‘ecogenomic sensor’, a device that can apply biomolecular analytical techniques *in-situ*.

11.7 Dr Birch focused on the Environmental Sample Processor (ESP) as a case study. The ESP currently employs low-density DNA probe and protein arrays to assess in near real-time the presence and abundance of specific organisms, their genes and/or metabolites. In addition, a 2-channel real-time polymerase chain reaction (PCR) module supports deployment of a variety of user-defined master mixes, primer/probe combinations and control templates. The ESP can also be used to preserve samples for a variety of laboratory tests once the instrument is recovered, including metatranscriptomic analyses of natural microbial populations. Typically deployed as a mooring, the ESP is being further developed to fit within an Autonomous Underwater Vehicle, adding never-before-seen mobility to ecogenomic sensors. Dr Birch highlighted the architecture of the ESP and its on-board analytical methods, presenting results of recent shallow and deep water field deployments, and its future directions in accessing unexplored regions of the ocean.

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87 Monterey Bay Aquarium Research Institute (MBARI), http://www.mbari.org/

11.8 In the subsequent discussion, the following points were raised:

(a) Sample collection and processing is a key aspect of marine ecosystem monitoring.

(b) In addition to the ability to recognise oceanic toxin blooms, the genomic analysis environmental DNA (eDNA) in seawater provides opportunities to look at changes in communities of marine animals (and especially microbes) as indicators of change. This could have application in studying the eco-system around sea or fresh water dumped munitions.

Subitem 11(c): Modular robotic toolbox for counter-CBRN support

11.9 Mr Grzegorz Kowalski (Industrial Research Institute for Automation and Measurements, PIAP, Poland[88]) discussed modular robotic platforms for counter-CBRN support.[89] Mobile robots used in security applications have mainly focused on improvised explosive device and ordinance disposal (IEDD and EOD), but are now seeing greater expansion into other specialised fields. Robots can be constructed for specific environments and applications (e.g. for operating in nuclear power plants) and equipped with dedicated auxiliary tools, so that only changes to the platform are required to fit the robots for different applications. One applications area, which is seeing interest, is support to counter-CBRN actions. Many robotic producers offer sensors and other devices, which can be integrated into the host mobile platforms. Mr Kowalski presented an overview the modular toolbox of forensic and the counter-CBRN robotic accessories developed at PIAP that offer high configurability and interoperability for the end-user.

11.10 The concept of the modular robotic toolbox assumes that the family of accessories can work independently from the host platform (even if this is a human) and can be controlled by various means chosen by the operator. The toolbox is based on software interfaces, which allow the user to adjust the set of accessories and their means of control to the specific needs of a mission, allowing ad-hoc reconfiguration on demand. Toolbox' devices use similar electronic subsystems for the realisation of the interfaces, and standardised mechanical attachments, such as NATO weapon rails.

11.11 In the subsequent discussion, the following points were raised:

(a) The approach described by Mr Kowalski, requires that sampling and analysis systems to be integrated into the robot are not developed by the engineers; rather they are sourced from manufacturers as ready to use components of the robot.

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88 Przemyslowy Instytut Automatuki i Pomarow (PIAP), http://piap.pl/

89 Modular robotic toolbox for counter-CBRN support; G. Kowalski, A. Wołoszczuk, A. Spronśka D. Buliński, F. Czubaczyński; In: Szewczyk R., Kaliczyńska M. (eds) *Recent Advances in Systems, Control and Information Technology*. *SCIT 2016. Advances in Intelligent Systems and Computing*; 2017, *543*, 396 – 408, Springer, Cham.

(b) The modular tool box concept relies on interoperability/configurability, handheld use, ease of maintenance, wireless control, remote measurement capability, platform independence, and maintaining an internal power source.

Subitem 11(d): Unmanned aerial vehicle equipped with CBRN – detection, identification and monitoring (DIM) capability to enhance chemical awareness

11.12 Dr Marcel van der Schans (TNO, The Netherlands[90]) presented the CBRN-DIM (Chemical Biological Radiological Nuclear – Detection, Identification, and Monitoring) project. The detection of toxic chemicals at and around secured areas and other critical infra structure is crucial and normally monitored by point detectors. The disadvantage of point detectors is that large numbers (organised in a network) are needed when a large area is to be monitored. DIM capability can help overcome such limitations and allow for measurements to be taken in areas that may be problematic for investigators to access without exposing themselves to dangerous conditions.

11.13 Standoff detectors can be placed on the border of a secured or contaminated area and used to monitor the surroundings. Passive standoff detectors can determine the presence of chemicals based on spectroscopy (infrared for example). However, these detectors can suffer from interference by weather conditions and other airborne chemicals. There is also a strong need for methods capable of detecting chemicals of interest at longer distances. A UAV equipped with DIM capabilities could fill this gap. In a National Technology Project (NTP), the Dutch Ministry of Defence sponsored a joint project between Delft Dynamics, a manufacturer of UAV’s, and TNO, to develop a prototype of a CBRN-drone. Dr van der Schans provided an overview of the operational concepts for this CBRN-DIM UAV, describing the design and experiments performed with integrated sensors and sampling systems. Disadvantages that he highlighted included small UAVs having limited payload capacity (typically 1-2 kg) and limited battery life, restricting their utility to a directed use, rather than a monitoring mode.

11.14 The CBRN-DIM UAV under construction in the NTP is equipped with a smart sampling system, consisting of a vacuum canister or helium diffusion sampler, which can be manually activated or triggered by an onboard generic detection system. Crucial in that respect is the location of sampling and detection systems to avoid the interference by downwash caused by the rotor blades of the UAV. Results of experiments showing the impact of downwash were discussed and an outlook given on future developments for CBRN-DIM UAV systems.

11.15 In the subsequent discussion, the following points were raised:

(a) The TNO design is based on the scenario of small chemical plumes where a UAV could have the capability to fly to the source, identify the chemical and take a sample. Retrieval of samples was discussed, noting that there are commercially available devices for recovering air samples with a UAV[91], and

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90 TNO: Toegepaste Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research), https://www.tno.nl/en/

91 See for example, the Sentroid Flying Laboratory DR1000 and the accessories available at: http://scentroid.com/scentroid-dr1000/

a suggestion was made that sticky touch pads could be used to pick up soil or transfer materials off a surface.

(b) The presentation highlighted many of the difficulties encountered when building customised systems. Noteworthy is the interference in signal produced by exhaust from gasoline powered UAVs, dictating battery operation was preferable despite the limited flight time this necessitated.

(c) The issue of data security was raised for UAVs with on-board detection systems. For sensor arrays, the data are only the electronic signals of the semiconductor sensor components, which would be difficult (or impossible) to use without the analysis algorithm and training data set developed for the sensor array; this suggests that hacking into the data stream might not be of any use. Mass spectrometers however could have stored spectral data which would be more informative if the system was to be hacked into, which seems unlikely (in a conflict zone, the greatest risk to a UAV would be that it could be shot down).

12. AGENDA ITEM TWELVE – International monitoring networks

12.1 Ms Farhat Waqar moderated a session focused on monitoring and collecting information from a broad variety of methodologies across international borders.

Subitem 12(a): Monitoring networks tracking biogeochemical changes in coastal and maritime environments from Argentina

12.2 Professor Andres Arias, (Instututo Argentino de Oceanografia, Argentina) reviewed the capabilities and collaborative scientific studies being performed in the Global Argentine Basin Array,[92] a part of the Ocean Observations Initiative (OOI)[93] Professor Arias explained how international scientific monitoring networks, like those of the OOI, can facilitate collaborations between researchers across scientific disciplines. He introduced the scientific networks currently working in Argentine urban, coastal and maritime environments which are performing both classical and novel remote sampling. The presentation described the tracking of persistent pollutants using passive monitoring (such as passive air- and XAD[94] samplers), classical bio-indicators, and autonomous maritime buoys and boats. In addition to furthering international scientific collaboration, the data generated by these monitoring networks have provided input to policy makers to inform strategies for land management, and have helped in the assessment of environmental vulnerabilities.

12.3 In the subsequent discussion, the following points were raised:

(a) Monitoring networks that bring together scientists across international borders are recognised for their value for science diplomacy. These efforts support the

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92 For additional information on the Global Argentine Basin Array, see: http://oceanobservatories.org/array/global-argentine-basin/

93 For additional information on the Ocean Observations Initiative, see: http://oceanobservatories.org/

94 XAD refers to highly absorbent resins that are used for continuous sampling of organic materials.

objectives of the Convention by promoting international scientific cooperation. Additionally, the data sets that inform policymakers serve to further facilitate valuable scientist-policymaker engagement.

(b) International monitoring networks also offer opportunities in outreach and awareness-raising, as they can serve to bring scientific experts together, as well to facilitate citizen science initiatives that engage the general public (this can also facilitate crowd sourcing of new ideas and innovative technologies). In the disarmament community, the international monitoring system[95] of the Comprehensive Nuclear Test Ban Treaty Organisation[96] plays a similar role.

Subitem 12(b): Remote sensing and open-source research for non-proliferation analysis: case studies from the MIIS Center for Nonproliferation Studies

12.4 Ms Catherine Dill (Middlebury Institute of International Studies (MIIS), James Martin Center for Nonproliferation Studies, United States of America[97]) discussed the use of remote sensing (specifically satellite imagery) for non-proliferation analysis. The applications of remote sensing capabilities, particularly satellite and aerial imagery, for security and non-proliferation topics are vast, with researchers exploring their applicability to chemical and biological security. Ms Dill described the use of optical satellite imagery to map, geolocate and monitor facilities of concern.[98,99] In addition to natural colour imagery, satellite imagery collected using non-visible wavelength light (for example thermal infrared and short-wave infrared) can be used to better understand the nature and operating status of facilities of interest and their surrounding environments. The Center for Nonproliferation Studies has been exploring the utility of short-wave infrared satellite imagery and hyperspectral satellite imagery for non-proliferation research with technology developers in the tech sector in nearby Silicon Valley. Ms Dill presented case studies where combinations of satellite and ground imagery were used to assess activities taking place at several facilities in the Democratic People’s Republic of Korea. She concluded with a discussion of applications for hyperspectral satellite imagery in non-proliferation research and potential areas of applicability for remote sensing for chemical security.

12.5 In the subsequent discussion, the following points were raised:

(a) Satellite image analysis for non-proliferation research requires access to a broad range of experts. In the review of images showing facilities that are

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95 CTBTO International Monitoring System (IMS), https://www.ctbto.org/verification-regime/

96 Comprehensive Nuclear test Ban Treaty Organisation (CTBTO), https://www.ctbto.org/

97 Middlebury Institute of International Studies (MIIS), James Martin Center for Nonproliferation Studies (CNS), http://www.nonproliferation.org/

98 Emerging Satellites for Non-Proliferation and Disarmament Verification; T. Patton, J. Lewis, M. Hanham, C. Dill, L. Vaccaro; Vienna Center for Disarmament and Non-Proliferation; January 2016. Available at: http://nonproliferation.org/vcdnp/wp-content/uploads/2016/06/160614_copernicus_project_report.pdf

99 Geo4nonpro.org: A geospatial crowd-sourcing platform for WMD verification; M. Hanham, C. Dill, J. Lewis, B. Kim, D. Schmerler, J. Rodgers; *CNS OCCASIONAL PAPER*; 2017; *28*. Available at: http://www.nonproliferation.org/op28-geo4nonpro-org-a-geospatial-crowd-sourcing-platform-for-wmd-verification/

relevant to chemical security for example, chemical engineering expertise for evaluating facilities would be crucial to make any conclusions.

(b) Crowd sourcing to annotate image data has been used successfully by agencies like NASA.[100] Non-proliferation researchers are also using this approach.[101] These annotations combined with other training data can help to optimise machine learning approaches that aid image analysis.

(c) Sourcing satellite images from multiple providers (sources) is recommended practice.

(d) With the increase in CubeSat companies and the complete Earth observation that they may potentially provide, there are opportunities to access images and information for evaluation through public outreach initiatives from satellite imagery providers.

(e) Other satellite imagery, from the Landsat programme for example, is available as open access data. Landsat satellite images have been used to estimate the levels of certain chemical elements in soil[102] and to identify toxic algae blooms.[103]

(f) An advantage of using the types of open-source information described by Ms Dill includes the ease and speed of accessing data, and the ability to readily share analysis results.

13. AGENDA ITEM THIRTEEN – Computer aided engineering tools applied to Chemical Weapons Convention implementation

13.1 Dr Bernard West moderated a session focused on the use of modelling tools that have useful applications in response to, and investigation of, chemical incidents.

13.2 Dr Evandro Nogueira discussed the use of Computer Aided Engineering Tools (CAE). These have been finding use across a variety of applications, including for innovation,[104] for chemical engineering education,[105] product development and

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100 NASA has a number of "citizen science" projects, some of which provide images to participants who annotate and classify features. All of the NASA citizen science projects can be found at: https://science.nasa.gov/citizenscientists

101 Project on crowdsourced imagery analysis; MIIS James Martin Center for Nonproliferation Studies. For further information see: http://www.geo4nonpro.org/

102 Mapping and estimation of chemical concentrations in surface soils using LANDSAT TM satellite imagery; B. Bhaskar, M. Sridhar, R. K. Vincent; in: N. Diodato (ed), *Satellite Communications*, 2010, Chapter 10, 183 – 189, *InTech*, DOI: 10.5772/9990.

103 For example: How Landsat data led to a breakthrough for Lake Erie toxic algal blooms; J. Ho, A. Michalak; Carnegie Science, https://landsat.gsfc.nasa.gov/how-satellite-data-led-to-a-breakthrough-for-lake-erie-toxic-algal-blooms/

104 Open computer aided innovation to promote innovation in process engineering; R. L. Floresa, J. P. Belaud, S. Negnya, J. M. Le Lanna; C*hemical Engineering Research and Design;* 2015, *103,* 90 – 107. DOI: 10.1016/j.cherd.2015.08.015.

105 Towards outcomes-based education of computer-aided chemical engineering; Z. N. Pintarič, Z. Kravanja; *Journal of Food Engineering;* 2016, *38*, 2367 - 2372. DOI: 10.1016/B978-0-444-63428-3.50399-4.

improvement,[106] chemical emergency response scenarios,[107] chemical reactor design,[108] blast explosion studies,[109] and the interaction of chemical agents with enzymes.[110] After first providing an overview, Dr Nogueira discussed how CAE tools could be applied to the implementation of the Convention across areas of disarmament, non-proliferation, assistance and protection, and international cooperation. Both freely available[111] and commercial[112] software packages, and their limitations were discussed, with Dr Nogueira reviewing how numerical, physical and phenomenological parameters should be set and post-processing analysis developed for the study of toxic chemical release.

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106 (a) Toward computer-aided food engineering: Mechanistic frameworks for evolution of product, quality and safety during processing; *Computer Aided Chemical Engineering*; 2016, *176*, 9 - 27. DOI: 10.1016/j.jfoodeng.2015.10.010. (b) Challenges and opportunities in computer-aided molecular design; L. Y. Ng, F. K. Chong, N. G. Chemmangattuvalappil; *Computers and Chemical Engineering*; 2015, *81*, 115 – 129. DOI: 10.1016/j.compchemeng.2015.03.009.

107 (a) Multiphase computational fluid dynamics simulation as a tool for planning emergencies with chemical agents; I. V. M. Barbosa, J. C. C. Pinto, E. S. Nogueira; *Revista Virtual de Química*; 2014, *6*, 795 - 814. DOI: 10.5935/1984-6835.20140048. (b) CFD dispersion modelling for emergency preparedness; M. Kisˇa, L. Jelemensky; *Journal of Loss Prevention in the Process Industries*; 2009, *67*, 97 – 104. DOI: 10.1016/j.jlp.2008.09.013. (c) Quantitative risk analysis of toxic gas release caused poisoning — A CFD and dose–response model combined approach; B. Zhang, G. Chen; *Process Safety and Environmental Protection*; 2010, *88*, 253 – 262. DOI:10.1016/j.psep.2010.03.003.

108 (a) Particle responses to flow field oscillations in heterogeneous polymerizations performed in tank reactors; W. M. Poubel, C. E. F. C. Silva, E. N. Souza, J. C. Pinto; *Macromolecular Reaction Engineering;* 2013, *8*, 374 – 391. DOI: 10.1002/mren.201300142. (b) Analysis of energy dissipation in stirred suspension polymerisation reactors using computational fluid dynamics; E. S. Nogueira, J. C. Pinto, A. S. Vianna; *Canadian Journal of Chemical Engineering*; 2012, *90*, 983 - 995. DOI: 10.1002/cjce.20611. (c) An experimental and CFD study of liquid jet injection into a partially baffled mixing vessel: A contribution to process safety by improving the quenching; J. Torré, D. F. Fletcherb, T. Lasuyec, C. Xuereba; *Chemical Engineering Science*; 2008, *63*, 924 – 942. DOI: 10.1016/j.psep.2010.03.003.

109 (a) Developments in vapour cloud explosion blast modeling; W. P. M. Mercx, A. C. Van Den Berg, C. J. Hayhurst, N. J. Robertson, K. C. Moran; *Journal of Hazardous Materials*; 2000, *7*, 301 – 319. DOI: 10.1016/S0304-3894(99)00085-0. (b) Using computational fluid dynamics (CFD) for blast wave predictions; O. R. Hansen, P. Hinze, D. Engel, S. Davis; *Journal of Loss Prevention in the Process Industries*; 2010, *23*, 885 - 906. DOI: 10.1016/j.jlp.2010.07.005.

110 (a) Molecular dynamics of the interaction of pralidoxime and deazapralidoxime with acetylcholinesterase inhibited by the neurotoxic agent tabun; A. S. Goncalves, T. C. C. Franca, A. Wilter, J. D. F Villar*; Journal of the Brazilian Chemical Society*; 2006, *17*, 968 - 975. DOI: 10.1590/S0103-50532006000500022. (b) Development of new acetylcholinesterase reactivators: Molecular modeling versus in vitro data; T. C. Ramalho, T. C. C. Franca, M. N. Renno, A. P. Guimaraes, E. F. F. Cunha, K. Kuca*; Chemico-Biological Interactions*; 2010, *185*, 73 - 77. DOI: 10.1016/j.cbi.2010.02.026.

111 (a) ALOHA® (Areal Locations of Hazardous Atmospheres, hazard modeling tool), United States Environmental Protection Agency, https://www.epa.gov/cameo/aloha-software (b) CAMEO® (Computer-Aided Management of Emergency Operations) software, United States Environmental Protection Agency, https://www.epa.gov/cameo (c) MARPLOT® (Mapping Application for Response, Planning, and Local Operational Tasks), United States Environmental Protection Agency, https://www.epa.gov/cameo/marplot-software (d) ANSYS® Student, http://www.ansys.com/products/academic/ansys-student

112 (a) PEAC® (Palmtop Emergency Action for Chemicals) Aristatek Inc. Software, http://www.aristatek.com/Newsletter/02%2005%20May/Description%20of%20the%20PEAC%20Tool.htm (b) ANSYS 18 CFD Software, http://www.ansys.com/products/release-highlights

13.3 In the subsequent discussion, the following points were raised:

(a) Dispersion models can be helpful if the data they generate can be correlated (validated) with real-world data. It is important to have accurate source terms, preferably derived from experimental studies in order to have confidence in the predictions.

(b) In this regard to applications relevant to the Convention, an example of dispersion modelling related to events in Syria using open source information (including weather reports and satellite imagery) to inform the model was recently published in a peer-reviewed scientific journal.[113]

14. AGENDA ITEM FOURTEEN – Breakout Groups

14.1 Workshop participants were divided into four breakout groups to address key questions related to innovative technologies and the implementation of the Convention.

14.2 The first breakout group facilitated by Mr Cheng Tang addressed the topic of "enhancing the capabilities of inspectors". Three questions were addressed.

(a) What are the essential capabilities for OPCW inspectors to conduct inspections or investigations? In regard to this question, these needs were identified:

(i) Safe access;

(ii) DIM capabilities (including sampling and analysis);

(iii) The ability to accurately record and document information (including for chain of custody purposes);

(iv) Communications; and

(v) Protection from hazards (health and safety).

(b) What kind of innovative technologies may be used to enhance current capabilities of inspectors? The breakout group focused on potentially enabling tools for investigative work in dangerous environments (that is, the points raised were not directed towards routine inspections), in this regard, the following technological capabilities were identified:

(i) Automated robotic platforms fitted with remote sensing tools for assessing and documenting investigation sites.

(ii) Technologies to aid on-site detection and *in-situ* sampling. Including technologies that can recognise biochemical change. These capabilities

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113 See for example: Assessment of the plume dispersion due to chemical attack on April 4, 2017, in Syria; K. Bhaganagar, S.R. Bhimireddy; *Nat. Hazards*, 2017. DOI: 10.1007/s11069-017-2936-x.

would help to better and more efficiently inform inspectors on the most valuable points at an investigation site where samples should be collected for further analysis.

(iii) Technologies that can aid in health and safety monitoring.

(iv) Advanced satellite imagery analysis tools (especially in regard to hyperspectral and non-visible wave length light images).

(c) In what ways can the innovative technologies identified in the previous question enhance the capability of inspectors? In regard to this question, the following areas were identified:

(i) Mission planning (for example, analysis tools for making more effective use of information available from satellite imagery, as well as the use of autonomous and remote systems such as UAVs).

(ii) Accessibility to otherwise dangerous or difficult to reach areas (especially through the use of autonomous and remote systems).

(iii) Protection (for example, stand-off detection capability; and wearable sensing technologies that can give early indications of exposure, providing enhanced personal protective equipment to ensure improved health and safety).

(iv) More confidence in data collection and results, especially with regard to measurements and detection (multiple and complementary devices to monitor and detect chemicals will provide multiple data streams and higher confidence in a result; recognising biochemical change would also provide access to biochemical markers of change that might prove useful in more robust confirmatory off-site analysis).

(d) The breakout group provided the following conclusions:

(i) Many of the technologies considered during the workshop have potential value for reducing risks to personnel operating in dangerous environments. Understanding how to most effectively use such tools could help in the development of advice for best practices for working under dangerous operational conditions, such as in a chemically contaminated environment.

(ii) Given the needs of inspectors when operating in dangerous environments, engagement with those developing and deploying suitable innovative tools could be of value. The science and technology review process may be a resource to identify such developers (and especially those with commercially available fieldable products) and the SAB could usefully facilitate engagement with these communities.

(iii) Training and scientific review workshops could both potentially serve as fora for reviewing new technologies and providing feedback to their developers in relation to operational needs and field suitability.

(iv) Engaging developers of enabling technologies is the best way to ensure that enabling tools are developed for the specific needs and operational requirements of inspectors. In this regard, it was noted that developing customised solutions and gaining access to new capabilities in some international organisations have been realised through public-private partnerships.[114]

14.3 The second breakout group facilitated by Mr Francois van Straten addressed the topic of "stand-off detection and early warning systems". Three questions were addressed.

(a) How can the latest detection technologies be integrated with social media, the internet, and existing humanitarian response structures to provide simple and cost effective early warning and identification of chemical threats to vulnerable populations in strife torn areas? In regard to this question, the following points were raised:

(i) Smartphones can provide initial information in two ways: by communicating information users "sense" themselves, or by making use of the detection capability of the device (which requires plug in sensors and/or mobile apps).

(ii) Social media and other unstructured data can also provide a means to identify an incident is occurring in real time,[115] however the reliability of such information is an issue. Integrating this kind of data with other sources of information, for example chemical analysis, first responder and medical care reporting, could help to provide more credible information about an incident. The capability to use such data in real time could be provided through an App restricted to use by appropriate authorities.

(b) What are the possibilities of using existing weather, agricultural, global positioning and reconnaissance satellite infrastructure to monitor the release of chemical clouds and identify the chemicals used? In regard to this question, the following points were raised:

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114 In particular, the International Atomic Energy Agency, for example: (a) Strengthening the IAEA: Technical Cooperation and Nuclear Security. Report of an International Working Group, June 2016, available at: http://www.psaonline.org/wp-content/uploads/2016/07/Strengthening-the-IAEA.pdf and, (b) Role of Private Sector in Sustainable Development Highlighted at IAEA Conference, https://www.iaea.org/newscenter/news/role-of-private-sector-in-sustainable-development-highlighted-at-iaea-conference

115 See for example: Crowdsourcing based social media data analysis of urban emergency events; Z. Xu, Y. Liu, J. Xuan, H. Chen, L. Mei; *Multimed Tools Appl*,; 2017, *6*, 11567 – 11584. DOI: 10.1007/s11042-015-2731-1.

(i) For chemical analysis, where the capability to identify a chemical is limited, confirmation of its structure by sampling and analysis will remain the most certain method for the foreseeable future.

(ii) The use of UAVs (which can be fitted with a variety of spectrometric tools) would be a complementary way to obtain chemical information. Existing UAV systems are currently best-suited to response/confirmation rather than early warning given limitations in flight time.

(iii) Incomplete daily (and time-of-day dependent) satellite coverage limits what can be observed. Complementary sets of image data may also be required to avoid losing information from clouds and other interferences. This could include multispectral and non-visible light imagery as well as UAV generated imagery.

(c) Following the Fukushima nuclear plant accident, mobile devices were quickly adapted to provide radiation monitoring capabilities. What different technical approaches are possible and how much progress has been made with regard to chemical detection on such devices? In regard to this question, the following points were raised:

(i) While there have been reports of smartphone based chemical agent[116] and toxic industrial chemical detection devices, these are research projects and probably more than 5-10 years away from fieldable and reliable use.

(ii) Given the value of miniaturised detection devices for field work, developments in this area could usefully remain a topic of interest in the science and technology review process.

(d) The breakout group provided the following conclusions:

(i) The Secretariat is encouraged to engage with developers of stand-off detection systems to explore the possibility of evaluating commercially available systems in training exercises.

(ii) Many new tools and technologies may seem well suited for early detection purposes; however they must be evaluated under field conditions in order to understand their utility and limitations (including false positive and false negative rates and operational suitability).

14.4 The third breakout group facilitated by Professor David Gonzalez addressed the topic of "collecting and integrating data streams, is there a need in the implementation of the Convention?" Two sets of questions were considered.

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116 Wireless, wearable toxic-gas detector: inexpensive sensors could be worn by soldiers to detect hazardous chemical agents; R. Matheson, *MIT News*, 30 June 2016, http://news.mit.edu/2016/wireless-wearable-toxic-gas-detector-0630

(a) How can the Convention benefit from the huge amount of data collected and processed by environmental monitoring? Is this useful data? Are there security concerns? In regard to these questions, the following points were raised:

(i) Such data have the potential to reveal information that would fall outside the boundaries set for routine inspections and especially industry inspections, making such data unsuitable under these mandates.

(ii) Environmental monitoring could potentially find use in contingency operations and/or investigations of alleged use. Satellite imagery, for example, allows visual inspection of areas where an incident could have taken place; hyperspectral, thermal and/or infrared images might identify features (especially in vegetation) that are indicative of the event.

(iii) Available data may be limited due to incomplete planetary satellite coverage, unavailability of multispectral and/or hyperspectral images, and there could be restricted access to images for proprietary or security reasons.

(iv) Collecting data on-sight using UAVs could be a valuable tool for investigation site surveillance. However there may also be limitations due to local regulations on the use of such equipment, and the possibility such UAVs could image areas that are restricted to investigators.

(v) An additional consideration on the use of environmental monitoring data is that to detect a meaningful change in relevant environmental indicators, an understanding of natural background signals and their variations is required. Data sets to establish these backgrounds may not be available.

(vi) As any given situation will have its own requirements for the types of information needed and the access required (including, but not limited to terrain, infrastructure, security constraints). How well suited a technology is for a given mission would need to be evaluated on a case by case basis.

(vii) Wearable technologies can also be thought of as a type of environmental monitor, with capabilities described in previous sections of this report.

(b) Big Data is increasingly handled by artificial intelligence systems, what are the advantages and the risks? Are there alternatives or is this an inevitable direction? In regard to these questions, the following points were raised:

(i) Advantages are increased effectiveness of analysis (provided the algorithms are adequately developed and trained). Disadvantages relate to data management and data security.

(ii) As data sets become larger and greater computational power is required for analysis, more cloud based analytics capabilities may be required. Ensuring that the security and confidentiality of data is maintained while using cloud servers and internet connected storage devices are an important issue.

(iii) Security of collections of audio, video, digital image, chemical analysis and other digitised investigation evidence are particularly sensitive. Staying up to date with encryption tools and secure storage devices (with redundancy to avoid loss of data) will be necessary.

14.5 The fourth breakout group facilitated by Dr Jonathan Forman addressed the topic of "opportunities for new technologies". Three questions were addressed.

(a) Considering the core activities of implementation of the Convention, which areas are most suited to new technologies? Which areas might be most suited to a rapid innovation approach to the use of new technologies? In regard to these questions, the following points were raised:

(i) The technologies discussed in the workshop have potential uses and applications across the four result areas for implementation of the Convention described in the 2017-2021 Medium Term Plan.[117] Specifically: "verification for continued confidence in compliance"; "capacity development to prevent and respond to the hostile use of toxic chemicals and to foster international cooperation"; "engagement to utilise others' capabilities"; and "an organisation that remains fit for purpose".

(ii) Rapid innovation approaches are best suited for training and education related activities. Opportunities to engage with technology developers and evaluate their tools under field conditions, where feedback can be provided, would be a useful way to gain access to new technologies.

(b) Is there a role for "innovation ecosystems" that could benefit the implementation of the Convention? How could this work? Do any already exist? In regard to these question, the following points were raised:

(i) Engaging with innovation communities would be a useful approach for the Secretariat. Bringing together transdisciplinary groups to share and discuss ideas is vital for meeting future challenges.

(ii) Opportunities to reach into these communities can be found during the science and technology review process, through the use of "crowd source" competitions (an approach that has been used for non-proliferation purposes, and especially with regard to innovative

117 "Medium-Term Plan of the Organisation for the Prohibition of Chemical Weapons, 2017 – 2021", EC-83/S/1 C-21/S/1, dated 8 April 2016. Available at: www.opcw.org/fileadmin/OPCW/EC/83/en/ec83s01_c21s01_e_.pdf

technologies),[118,119] by engaging with and supporting innovation initiatives, and engaging with private sector technology developers.

(c) What would be the most effective process for recognising and evaluating new technologies with applications beneficial to the implementation of the Convention? In regard to this question, the following points were raised:

(i) Learning about the needs and challenges faced by inspectors was essential for discussion of where new technologies may be beneficial during the Rio workshop. In this regard, interactions of inspectors with innovation communities and technology developers could usefully serve to recognise technologies of interest.

(ii) The interaction of inspectors, as well as staff from the OPCW Laboratory, with the science and technology review process also serves as a source of ideas and capabilities to consider.

(iii) Evaluation of new technologies is well suited for training and education activities, where active feedback can be given to technology developers.

15. AGENDA ITEM FIFTEEN – Closure of the Workshop

The Chairperson closed the workshop at 12:20 on 5 July 2017.

16. AGENDA ITEM SIXTEEN – Adoption of the Report

The drafting committee considered and adopted the report of the workshop on "Innovative Technologies for Chemical Security".

ACKNOWLEDGEMENT

The SAB acknowledges the contributions of Ms Darcy van Eerten of the OPCW for her contributions to sourcing many of the references included in this report.

Annex : List of Participants at the Workshop on Innovative Technologies for Chemical Security

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118 Examples of crowd source challenges (all have been awarded) with disarmament focus include: (a) N Square challenge: building a nuclear security innovation network, innocentive.com/ar/challenge/9933708 (b) Mobile and novel chemical warfare agent destruction and/or neutralization www.innocentive.com/ar/challenge/9932942 (c) 2013 Innovation in arms control challenge: What information technology tools and concepts can support future arms control inspections? innocentive.com/ar/challenge/9933381 (d) 2012 Innovation in arms control challenge: How can the crowd support arms control transparency efforts? www.innocentive.com/ar/challenge/9933144

119 International Atomic Energy Agency (IAEA) Technology Challenges: (a) 2017 Robotics Challenge, https://challenge.iaea.org/robotics; (b) 2016 Digital image processing for the Improved Cerenkov Viewing Device (ICVD), https://www.ungm.org/Public/Notice/45386

Annex

LIST OF PARTICIPANTS AT THE WORKSHOP ON INNOVATIVE TECHNOLOGIES FOR CHEMICAL SECURITY

	Participant	Institution
1.	Professor Cristhian Manuel Durán Acevedo	Universidad De Pamplona, Colombia
2.	Dr Andrés Arias	Instututo Argentino de Oceanografia
3.	Dr Jim Birch	Monterey Bay Aquarium Research Institute, United States of America
4.	Dr Oscar Björnham	Swedish Defence Research Agency (FOI), Umeå, Sweden
5.	Dr Veronica Borrett*	BAI Scientific and Honorary Fellow, University of Melbourne, Australia
6.	Dr Paulo Cabral	CBRN Institute, Brazil
7.	Dr Mark Cesa+	International Union of Pure and Applied Chemistry
8.	Professor Luiz Davidovich	Academia Brasileira de Ciências
9.	Dr Jorge Andrés Díaz	University of Costa Rica, Costa Rica
10.	Ms Catherine Beatrice Dill	Middlebury Institute of International Studies at Monterey, United States of America
11.	Professor Vitor F. Ferreira+	Universidade Federal Fluminense, Brazil
12.	Dr Jonathan Forman+	Organisation for the Prohibition of Chemical Weapons
13.	Mr Sérgio Frazão	Executive Secretary for the Brazilian National Authority, Brazil
14.	Professor David González*	Department of Chemistry, University of the Republic of Uruguay and Ministry of Education, Montevideo, Uruguay
15.	Ms Katarína Grolmusová	Organisation for the Prohibition of Chemical Weapons
16.	Mr George Harris	Basil Leaf Technologies, United States of America
17.	Dr Jo Husbands+	National Academies of Sciences, Engineering, and Medicine, United States of America
18.	Dr Ricardo Inamasu	Embrapa Labex, Brazil
19.	Dr Zrinka Kovarik*	Institute for Medical Research and Occupational Health, Zagreb, Croatia
20.	Mr Grzegorz Kowalski	Industrial Research Institute for Automation and Measurements PIAP, Poland
21.	Mr Matheus Kuska	University of Bonn, Germany
22.	Dr Xiao Li	Stanford University, United States of America
23.	Dr Nicia Mourão	Universidade Federal do Rio de Janeiro, Brazil
24.	Mr Jarrett Nguyen+	National Academies of Sciences, Engineering, and Medicine, United States of America
25.	Dr Evandro de Souza Nogueria*	Brazilian Ministry of Science, Technology, Innovation and Communications (MCTIC), Brasilia, Brazil

	Participant	Institution
26.	Professor Elisa Orth	Federal University of Parana, Brazil
27.	Dr Richard Ozanich	Pacific Northwest National Laboratory, United States of America
28.	Ms Marlene Payva+	Organisation for the Prohibition of Chemical Weapons
29.	Professor Ponnadurai Ramasami*	University of Mauritius
30.	Dr Syed K. Raza*	Institute of Pesticide Formulation Technology (IPFT), India
31.	Professor Thiago Renault	Innovation Agency of the Fluminense Federal University, Brazil
32.	Professor Ahmed Saeed*	Sudan University of Science and Technology, Khartoum, Sudan
33.	Professor Murilo Santhiago	Brazilian Nanotechnology National Laboratory (LNNano), Brazilian Center for Research in Energy and Materials (CNPEM)
34.	Dr Marcel van der Schans	TNO, Netherlands
35.	Mr Marcos Cortesão Barnsley Scheuenstuhl+	Academia Brasileira de Ciências
36.	Mr Vitor Vieira de Oliveira Souza+	Academia Brasileira de Ciências
37.	Mr Francois van Straten*	Chemical Weapons Working Committee, South Africa
38.	Mr Cheng Tang*+[120]	Office for the Disposal of Japanese Abandoned Chemical Weapons, Ministry of National Defence, China
39.	Dr Christopher Timperley*+[121]	Defence Science and Technology Laboratory (Dstl), Porton Down, United Kingdom of Great Britain and Northern Ireland
40.	Dr Camly Tran+	National Academies of Sciences, Engineering, and Medicine, United States of America
41.	Mr Guy Valente	Organisation for the Prohibition of Chemical Weapons
42.	Ms Farhat Waqar*	Pakistan Atomic Energy Commission
43.	Dr Bernard West+	International Union of Pure and Applied Chemistry, Committee on Chemical Industry
44.	Professor Volodymyr Zaitsev*	Taras Shevchenko National University of Kyiv, Ukraine
45.	Professor Aldo Zarbin+	Sociedade Brasilia de Química

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+Member of the workshop organising and/or planning committee.

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120 Vice-Chairperson, OPCW SAB.
121 Chairperson, OPCW SAB.