Investigative Science and Technology

REPORT OF THE SCIENTIFIC ADVISORY BOARD'S TEMPORARY WORKING GROUP

December 2019

ORGANISATION FOR THE PROHIBITION
OF CHEMICAL WEAPONS

In memory of Mr Valentin Rubaylo, 1946 – 2019

A dear colleague, a committed member of the SAB, a good friend

Investigative Science and Technology

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Adopted by the Temporary Working Group on Investigative Science and Technology at its Fifth meeting on 20 November 2019.

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Executive Summary

Since 2013, the OPCW Technical Secretariat (hereinafter, the "Secretariat") is increasingly being tasked to undertake non-routine missions, for example, verifying the removal and destruction of chemical weapons from the Syrian Arab Republic[1] and Libya,[2] as well as fact-finding and investigation,[3] with the collection and evaluation of oral, material and digital evidence of the use of chemical weapons. In 2014, an OPCW Fact-Finding Mission (FFM) began collecting information to determine whether or not chemical weapons had been used in the Syrian Arab Republic.[4] In 2015, the UN Security Council created the OPCW-United Nations Joint Investigative Mechanism (JIM) to identify those involved in the use of chemical weapons in Syria.[5] The findings of the FFM provided the starting point for the JIM.

In June 2018, the Conference of the States Parties tasked the OPCW Director-General to "put in place arrangements to identify the perpetrators of the use of chemical weapons" under specified circumstances.[6] In addition, the Director-General was mandated to provide "technical assistance to identify those who were perpetrators, organisers, sponsors or

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1 For additional information, see: (a) OPCW-UN Joint Mission ; https://opcw.unmissions.org/mandate-and-timelines. (b) "Removal and Destruction of Syrian Chemical Weapons" (infographic); www.opcw.org/sites/default/files/documents/files/Syra_Infographic.pdf.

2 For additional information, see: Libya and the OPCW; www.opcw.org/media-centre/featured-topics/libya-and-opcw.

3 For additional information on OPCW's missions in the Syrian Arab Republic, see: Syria and the OPCW; www.opcw.org/media-centre/featured-topics/syria-and-opcw. For recent updates see also (a) "Progress in the Elimination of the Syrian Chemical Weapons Programme" (EC-93/DG.5, dated 24 December 2019); www.opcw.org/sites/default/files/documents/2019/12/ec93dg05%28e%29.pdf. (b) "Progress in the Elimination of the Syrian Chemical Weapons Programme" (EC-93/DG.3, dated 25 November 2019); www.opcw.org/sites/default/files/documents/2019/11/ec93dg03%28e%29.pdf. (c) "Progress in the Elimination of the Syrian Chemical Weapons Programme" (EC-93/DG.1, dated 28 October 2019); www.opcw.org/sites/default/files/documents/2019/10/ec93dg01%28e%29_0.pdf.

4 For further information on the Fact-Finding Mission, see: www.opcw.org/fact-finding-mission. See also (a) "Update of the Activities Carried out by the OPCW Fact-Finding Mission in Syria" (S/1798/2019, dated 3 October 2019). (b) "Summary Update of the Activities Carried out by the OPCW Fact-Finding Mission in Syria" (S/1677/2018, dated 10 October 2018); www.opcw.org/sites/default/files/documents/2018/10/s-1677-2018%28e%29.pdf. (c) "Summary Update of the Activities Carried Out by the OPCW Fact-Finding Mission in Syria in 2016" (S/1445/2016, dated 27 December 2016); www.opcw.org/sites/default/files/documents/2018/11/s-1445-2016_e_.pdf. (d) "Summary Report of the Work of the OPCW Fact-Finding Mission in Syria Covering the Period from 3 to 31 May 2014" (S/1191/2014, dated 16 June 2014); www.opcw.org/sites/default/files/documents/S_series/2014/en/s-1191-2014_e_.pdf.

5 An OPCW-UN Joint Investigative Mechanism Fact Sheet is available at: https://unoda-web.s3accelerate.amazonaws.com/wp-content/uploads/2016/08/JIM-Fact-Sheet-July2016.pdf. See also: (a) "First report of the Organisation for the Prohibition of Chemical Weapons United Nations Joint Investigative Mechanism" (United Nations Security Council, S/2016/142, dated 12 February 2016); http://undocs.org/S/2016/142. (b) "Third report of the Organisation for the Prohibition of Chemical Weapons-United Nations Joint Investigative Mechanism (United Nations Security Council" (S/2016/738, dated 24 August 2016); http://undocs.org/S/2016/738. (c) "Fourth report of the Organisation for the Prohibition of Chemical Weapons-United Nations Joint Investigative Mechanism" (United Nations Security Council, S/2016/888, dated 21 October 2016); http://undocs.org/S/2016/888. (d) "Fifth report of the Organisation for the Prohibition of Chemical Weapons-United Nations Joint Investigative Mechanism" (United Nations Security Council. S/2017/131, dated 13 February 2017); http://undocs.org/S/2017/131. (e) "Sixth report of the Organisation for the Prohibition of Chemical Weapons-United Nations Joint Investigative Mechanism" (United Nations Security Council, S/2017/552, dated 28 June 2017); http://undocs.org/S/2017/552. (f) "Seventh report of the Organisation for the Prohibition of Chemical Weapons-United Nations Joint Investigative Mechanism" (United Nations Security Council, S/2017/904, dated 26 October 2017); http://undocs.org/S/2017/904.

6 "Decision: Addressing the Threat from Chemical Weapons Use" (C-SS-4/DEC.3, dated 27 June 2018); www.opcw.org/sites/default/files/documents/CSP/C-SS-4/en/css4dec3_e_.doc.pdf.

otherwise involved in the use of chemical weapons" to any State Party that was investigating the possible use of chemical weapons on its territory and requested such assistance.[7]

Alongside these non-routine missions, the OPCW has also responded to a variety of requests for technical assistance missions in the Syrian Arab Republic,[8] Iraq,[9] and the United Kingdom of Great Britain and Northern Ireland.[10]

These missions have placed the Secretariat into new situations, which fall outside the provisions for investigation of alleged use or challenge inspection under Article IX and X of the Convention, yet with objectives directly related to Article I of the Convention. Since these new missions are even more demanding from a technical and forensic standpoint than the missions customarily performed by the Secretariat, the Director-General asked the Scientific Advisory Board to conduct an in-depth review of methods and technologies used for investigative work that would be relevant to the Secretariat. For this purpose, the Director-General established a Temporary Working Group (TWG) of the SAB on Investigative Science and Technology,[11] which convened its first meeting on 12 February 2018[12] (see Annex 1 for the terms of reference and Annex 3 for the TWG's membership).

The TWG held five meetings[13] and presented three interim reports to the SAB at the Board's Twenty-Seventh[14] and Twenty-Eighth[15] Sessions. The TWG received more than 100

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7 ibid, paragraph 20.

8 See for example: "Report on the Special Mission Conducted in Response to the Requests and Information Received from the Syrian Arab Republic Through Notes Verbales Dated 6, 16, and 20 November 2017, 28 December 2017, and 8 and 22 January 2018" (S/1596/2018, 2 March 2018).

9 See for example: For example: "Report of the Technical Assistance Visit to Iraq" (S/1559/2017, dated 6 December 2017).

10 See: (a) "Summary of the Report on Activities Carried Out in Support of a Request for Technical Assistance by the UK (Technical Assistance Visit TAV/03/18 and TAV/03B/18, "Amesbury Incident")" (S/1671/2018, dated 4 September 2018); www.opcw.org/sites/default/files/documents/S_series/2018/en/s-1671-2018_e_.pdf. (b) "Summary of the Report on Activities Carried Out in Support of a Request for Technical Assistance by the United Kingdom of Great Britain and Northern Ireland" (Technical Assistance Visit TAV/02/18)" (S/1612/2018, dated 12 April 2018); www.opcw.org/sites/default/files/documents/S_series/2018/en/s-1612-2018_e___1_.pdf.

11 (a) See paragraphs 8 to 9 of "Response to the Report of the Twenty-Fourth Session of the Scientific Advisory Board" (EC-84/DG.9, dated 18 January 2017); www.opcw.org/sites/default/files/documents/EC/84/en/ec84dg09_e_.pdf. (b) see paragraphs 12.3 to 12.5 of Report of the Scientific Advisory Board at its Twenty-Fifth Session" (SAB-25/1*, dated 31 March 2017); www.opcw.org/sites/default/files/documents/SAB/en/sab2501_e_.pdf. (c) See paragraphs 11.1 to 11.3 of "Report of the Scientific Advisory Board at its Twenty-Sixth Session" (SAB-26/1, dated 20 October 2017); www.opcw.org/sites/default/files/documents/SAB/en/sab-26-01_e_.pdf.

12 "Summary of the First Meeting of the Scientific Advisory Board's Temporary Working Group on Investigative Science and Technology" (SAB-27/WP.1, dated 26 February 2018), www.opcw.org/sites/default/files/documents/SAB/en/sab-27-wp01_e_.pdf.

13 (a) Ibid. (b) "Summary of the Second Meeting of the Scientific Advisory Board's Temporary Working Group on Investigative Science and Technology" (SAB-28/WP.2, dated 21 January 2019): www.opcw.org/sites/default/files/documents/2019/01/sab28wp02%28e%29.pdf. (c) "Summary of the Third Meeting of the Scientific Advisory Board's Temporary Working Group on Investigative Science and Technology" (SAB-28/WP.3, dated 4 June 2019): www.opcw.org/sites/default/files/documents/2019/06/sab-28-wp03%28e%29.pdf. (d) "Summary of the Fourth Meeting of the Scientific Advisory Board's Temporary Working Group on Investigative Science and Technology" (SAB-29/WP.1, dated 25 November 2019); www.opcw.org/sites/default/files/documents/2019/11/sab-29-wp01%28e%29.pdf. (e) The fifth and final meeting was held from 18 to 20 November, during this meeting the final report was drafted.

briefings from experts from a wide range of fields relevant to the practice of investigative work, including but not limited to investigational chemical analysis, evidence collection, forensic sciences, informatics, crime scene reconstruction, toxicology, and implementation of the Convention. For detailed consideration of the issues raised in the terms of reference, the TWG organized its discussions into the six sub-groups:

A: Forensic methods and capabilities.

B: Data collection and management (chain of custody; data management best practices).

C: Detection and analysis.

D: Integrity of the scene and evidence collection.

E: Provenance of chemicals.

F: Proposals for methodologies, procedures, technologies and equipment for investigative purposes.

Under the June 2018 CSP decision, the Secretariat has been directed to identify those involved in the use of chemical weapons in Syria. Attribution, i.e. the determination of responsibility for the use of chemicals or other actions prohibited by the Convention, is in the end a judgement drawing on a wide range of technical data and other kinds of information. Technical procedures, for example, chemical analyses that link traces of material found in a sample to a source are extremely valuable but are only one of many inputs into an attribution determination. Seldom will sample analysis alone be sufficient for a determination of responsibility.

OPCW fact-finding missions and investigations, for example those related to the use of chemical weapons, involve grave political and legal issues and therefore require the highest standards. The findings from such missions will receive intense scrutiny not only from Member States, but more generally. Furthermore, the Secretariat's involvement in an investigation is likely to be part of a larger process, where its findings are ultimately transferred to another mechanism for further review and possibly legal action. The Secretariat must ensure that the methods and approaches used to collect, and process information will meet the requirements of those who will ultimately receive and make decisions based on the information provided. For these reasons, the Secretariat should consider enlisting a forensic advisor with broad experience in forensic science and international law to provide advice to the Director-General and the policy-making organs. An independent external expert could be considered for this important role. Furthermore, rigorous forensic procedures should be incorporated into Recommended and Standard Operating Procedures (R/SOPs).

Investigations pose extraordinary information management challenges. Since information generated in an investigation will be highly sensitive politically and could lead to decisions by international policy-making organs, including the United Nations Security Council

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[14] See paragraphs 10.1 to 10.4 of "Report of the Scientific Advisory Board at its Twenty-Seventh Session" (SAB-27/1, dated 23 March 2018); www.opcw.org/sites/default/files/documents/SAB/en/sab-27-01_e_.pdf.

[15] See paragraphs 9.4 to 9.9 of "Report of the Scientific Advisory Board at its Twenty-Eighth Session" (SAB-28/1, dated 14 June 2019); www.opcw.org/sites/default/files/documents/2019/09/sab-28-01%28e%29_0.pdf.

(UNSC), or to national or international judicial action, it should be managed according to stringent forensic standards. This means managing it separately from information related to routine verification activities. Furthermore, the information management capability for such information must be maintained continuously, so that information is properly protected and available whenever it is needed, and the information management capability does not need to be recreated when a new investigation is mandated. Partnering with another international body in the United Nations (UN) system that maintains such a capability on a continuing basis might be explored to enable the OPCW to sustain a long-term capability for management of sensitive information.

Given the wide range of possible scenarios and toxic agents, the OPCW cannot possess all of the forensic expertise in-house that might conceivably be needed in a future investigation. The Secretariat should in advance establish working relationships with forensic science organisations, laboratories, and experts to ensure that the Secretariat has a network that can provide advice and analytical services on short notice. In particular, with regard to the need for access to a diversity of forensic and technical capabilities, consideration could be given to accessing those capabilities through service level agreements (SLA).

The use of toxic industrial chemicals (TICs) as weapons vividly demonstrates that the Secretariat's investigative capabilities must extend beyond the well-known chemical warfare agents, such as the mustard and nerve agents. The Secretariat should ensure that it has access to capabilities for verification and response to threats from non-traditional agents, such as newly scheduled agents[16] and central nervous system (CNS)-acting chemicals. Rather than attempt to develop all these capabilities in-house, the Secretariat should draw upon established sources, expert communities, chemical industry and equipment manufacturers to efficiently gain access to knowledge and capabilities.

Biological toxins, which are poisonous substances produced by living systems, pose particular investigative challenges, since they are at the interface of chemical and biological agents. Some toxins, such as saxitoxin, ricin, staphylococcal enterotoxin B, and botulinum toxins have been weaponized in the past.[17] In many cases, a number of closely related, but distinct, toxins possess very similar properties. Furthermore, analyses of low-molecular weight toxins, such as saxitoxin, require very different methods from analyses of high-molecular weight toxins, such as ricin. Relatively few laboratories are skilled in both types of analyses. A new TWG could be considered to enable the OPCW to understand how to ensure that the Secretariat has access to capabilities for analyses of a broad range of biological toxins.

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16 (a) "Consolidated Text of Adopted Changes to Schedule 1 of the Annex on Chemicals to the Chemical Weapons Convention" (S/1820/2019, dated 23 December 2019); www.opcw.org/sites/default/files/documents/2019/12/s-1820-2019%28e%29.pdf. (b) "Decision: Changes to Schedule 1 of the Annex on Chemicals to the Chemical Weapons Convention" (C-24/DEC.5, dated 27 November 2019); www.opcw.org/sites/default/files/documents/2019/11/c24dec05%28e%29.pdf. (c) "Decision: Technical Change to Schedule 1(A) of the Annex on Chemicals to the Chemical Weapons Convention" (C-24/DEC.4, dated 27 November 2019); www.opcw.org/sites/default/files/documents/2019/11/c24dec04%28e%29.pdf. (d) See also "Response to the Director-General's Request to the Scientific Advisory Board to Provide Advice on New Types of Nerve Agents" (SAB-28/WP.1, dated 3 July 2018).

17 (a) "Military importance of natural toxins and their analogs". V. Pitschmann, Z. Hon; *Molecules*, 2016, *21*, 556. DOI: 10.3390/molecules21050556. (b) "Biological toxins of potential bioterrorism risk: Current status of detection and identification technology". B. G. Dorner, R. Zeleny, K. Harju, J A. Hennekinne, P. Vanninen, H. Schimmel, A. Rummel; *Trends in Anal. Chem.*; 2016, *85*, 89-102. DOI: 10.1016/j.trac.2016.05.024.

Investigations that seek to establish whether or not chemical weapons have been used, but also who was involved in their use, require the Secretariat to have access to capabilities to establish the source of the chemical and the link to a perpetrator/s. The field of chemical forensics seeks to provide information on the provenance of chemical traces, based for example on characteristic impurities, by-products of the synthesis route or other chemical signatures. Determinations, however, depend on having relevant reference materials. The OPCW should maintain a reference collection of chemical warfare agent-associated samples. Additionally, the OPCW and the Designated Laboratories might consider actively supporting international research in this field. This could include engaging with, and where possible participating in, projects of the Chemical Forensics International Technical Working Group (CFITWG).[18] To better understand the body of scientific information and the best approaches to provenancing, a new TWG could be considered on the provenancing of samples of chemicals relevant to the Convention.

Investigation of alleged use of chemical weapons presents many similarities to a criminal investigation. Tools developed for national law enforcement purposes, for example, equipment for 3D documentation of the site, for maintaining and recording the chain of custody for materials, for hazard evaluation, and for managing large volumes of sensitive and varied information have direct relevance for OPCW non-routine missions. Furthermore, opportunities to make use of digital tools and technologies that are being developed and deployed for collection of verifiable information should be explored. Such procedures can make use of digital tools and technologies that are being developed and deployed for collection of verifiable information unaltered from its original form, substantiated by time stamps and geolocation data

Equipment for rapid on-site detection and tentative identification of toxic chemicals at an alleged attack site is important to enable OPCW personnel to evaluate the operational hazards posed by the site and to identify the areas of greatest evidentiary relevance to their mission. Such equipment should not only be capable of detecting the well-known nerve and mustard agents, but also high hazard TICs and other potential chemical threat agents, such as newly scheduled agents (e.g. novichoks[16d]), CNS-acting chemicals (e.g. fentanyls)[19] or biological toxins (e.g. ricin). A wide variety of detection devices are commercially available or in development. The Secretariat should systematically evaluate such devices in relation to the operational needs of inspectors and identify new capabilities that need to be developed.

As noted throughout this report, equipment and procedures that are potentially relevant to OPCW non-routine missions are being developed for a wide variety of other purposes. In view of the rapid development of technology and methods in fields potentially relevant to OPCW non-routine missions, the Secretariat should strengthen its ability to identify, evaluate and adopt new technologies and equipment. Consideration should be given to formalising a modest technology evaluation and adaptation program in the regular budget. Furthermore,

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[18] For further information on the CFITWG, see (a) "Chemical Forensics". C. G. Fraga; *Talanta*; 2018, 186, *585*. DOI: 10.1016/j.talanta.2018.04.057. (b) paragraphs 12.1 to 12.2 of the report of the First Meeting of the TWG, cited in footnote 12; (c) paragraphs 11.7 to 11.8 of the report of the Second Meeting of the TWG, cited in footnote 13; (d) paragraphs 5.1 to 5.2 of the report of the Third Meeting of the TWG, cited in footnote 13; and (e) paragraphs 6.1 to 6.5 of the report of the Fourth Meeting of the TWG, cited in footnote 13.

[19] (a) "Central nervous system-acting chemicals and the Chemical Weapons Convention: a former scientific adviser's perspective". R. J. Mathews; *Pure Appl. Chem.*; 2018, *90(10)*, 1559–1575, DOI: 10.1515/pac-2018-0502. (b) "Central nervous system (CNS) - Acting Chemicals" (infographic); www.opcw.org/sites/default/files/documents/2019/08/CNS%20Acting%20Chemicals.pdf.

consideration should be given to creating a program for systematic, continuing technology support by Member States, similar to that conducted by the International Atomic Energy Agency (IAEA).

In a fact-finding or investigation mission regarding alleged use of chemical weapons, information should be obtained directly at the relevant location by OPCW technical personnel, where possible. Experience has demonstrated, however, that it may be too dangerous for OPCW personnel to visit a site and information must be obtained through other means. Recent and on-going technical developments, however, may provide possibilities for doing so. The Secretariat should actively explore the use of technology, such as automated ground vehicles, drones, GPS-enabled video/still cameras and smartphone applications, that could provide authenticated on-site information, even if operated by non-OPCW personnel. In addition, high-quality commercial satellite imagery is now readily available and effective for site evaluation. Furthermore, the Secretariat should develop procedures and equipment that would allow non-OPCW personnel to collect environmental or biomedical samples, and transfer them to OPCW custody, in a forensically-sound manner.

Non-routine missions present unique challenges, both for the conduct of on-site activities and for the sustainability of the missions. The Secretariat should make a concerted and continuing effort to involve current and former OPCW personnel who have participated in such missions to provide advice on operating procedures, practices, and equipment for non-routine missions. This effort should include support for the mental well-being of inspectors both during the mission and afterwards.

One new type of non-routine mission, providing technical investigative assistance to a State Party, poses unique and highly complex technical, forensic, and legal issues, since it could result in personnel becoming involved in a process leading to domestic or international criminal prosecution. An example would be a case of suspected chemical terrorism. The Secretariat should identify and carefully explore technical, forensic, and legal issues involved in providing technical investigative assistance to a State Party and inform Member States of the findings.

This report presents formal recommendations and the findings of the TWG that informed the advice.

Recommendations

The OPCW was established, under the General Provisions of Article VIII of the Chemical Weapons Convention (hereinafter, "the Convention"), to implement the provisions of the Convention, including those for international verification of compliance. The June 2018 States Parties decision on addressing the threat from chemical weapons use,[6] affirmed that whenever chemical weapons use occurs on the territory of a State Party, "those who were the perpetrators, organisers, sponsors or otherwise involved should be identified". The decision noted "the added value of the Secretariat conducting an independent investigation of an alleged use of chemical weapons with a view to facilitating universal attribution of all chemical weapons attacks".

OPCW non-routine investigative and fact-finding missions with forensic components (collection and evaluation of oral, material and digital evidence) have placed the Secretariat into situations previously thought unlikely. These missions fall outside provisions for investigations of alleged use (IAUs) or challenge inspections (CIs) under Articles IX and X of the Convention, yet have objectives that contain similar aspects. To effectively carry-out these non-routine missions, the Secretariat must adopt approaches, develop tools and use methodologies suited to new and unfamiliar scenarios. This necessitates the availability of adequate resources, both in terms of staff and equipment and the need to develop relationships and arrangements with a broader network of technical communities. It is crucial to maintain the competence of staff and to make effective use of mechanisms within the Convention to meet the challenges posed by new and unfamiliar circumstances. Highly qualified staff members, with suitable training, skillsets, room for initiative and support by subject matter experts are required to ensure adaptability in the face of changing circumstances. The TWG makes the following recommendations in response to the general directives and specific questions posed by its terms of reference (see Annex 1).

Which methods and capabilities used in the forensic sciences could usefully be developed and/or adopted for Chemical Weapons Convention-based investigations? *TOR sub-paragraph 4(a).*

Recommendation 1: Appoint a forensic advisor with broad experience in forensic science, forensic examinations and international law to provide advice to the Director-General and the OPCW. An independent external expert could be considered.[20]

- When undertaking investigations, inspection teams would benefit from having a forensic adviser available for consultancy to provide forensic advice off-site, for optimal planning and conduct of investigative activities to ensure they meet international forensic standards, take advantage of modern forensic methods, and incorporate the broad range of available forensic expertise.
- For further information see the considerations of TWG Sub-Group A.

Recommendation 2: Create ownership by engaging the Secretariat in the integration of forensic R/SOPs into the OPCW workflows.

- A working group of Secretariat staff and forensic experts could be established to integrate forensic practices into relevant R/SOPs, and applications and technologies into the OPCW workflows for non-routine missions. This working group could also advise on the Secretariat's training curriculum.
- For further information see the considerations of TWG Sub-Group A.

Recommendation 3: Ensure that the technical findings of an investigation undergo an objective review consistent with forensic best practice to provide the Director-General with an additional level of quality assurance.

- Reviewers could be engaged by the OPCW on an anonymous basis and be appointed from external organisations. They would have recognised expertise in technical fields and/or forensic science relevant to the specific investigation.
- For further information see the considerations of TWG Sub-Group A.

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20 This recommendation was submitted to the Director-General prior to publication of this report. See paragraphs 1.3 to 1.4 and 9.6 to 9.8 of: "Report of the Scientific Advisory Board at its Twenty-Eighth Session" (SAB-28/1, dated 14 of June 2019); www.opcw.org/sites/default/files/documents/2019/09/sab-28-01%28e%29_0.pdf.; and see also the paragraph 10 of "Response to the Report of the Twenty-Eighth Session of the Scientific Advisory Board" (EC-92/DG.12, dated 9 September 2019); www.opcw.org/sites/default/files/documents/2019/09/ec92dg12%28e%29.pdf.

What are the best practices and analysis tools used in the forensic sciences for effectively cross-referencing, validating, and linking together information related to investigation sites, materials collected/analysed and individuals interviewed? *TOR sub-paragraph 4(b)*.

Recommendation 4: Review existing relevant R/SOPs. These should be reviewed together with an expert forensic consultant to ensure that they are forensically sound and fit for purpose, suitable for inclusion in a forensic case file and able to meet the requirements of the end user.

- Effectively cross-referencing the information collected across an investigation is best accomplished through the establishment of a forensic case file containing all components, including R/SOPs aligned to meeting the mandate of the end user. OPCW R/SOPs used to obtain evidence, images, interviews and other information must be forensically sound and suitable to build a forensic case file.
- For further information see the considerations of TWG Sub-Group B.

What are the best practices for management of data collected in investigations including compilation, curation, and analytics? *TOR sub-paragraph 4(c)*.

Recommendation 5: Ensure that Secretariat staff tasked with either reviewing or creating R/SOPs for forensic investigations understand forensic case management systems.

- An inspection team working in an investigative capacity in response to an alleged incident, is effectively undertaking a forensic investigation. Having inspectors learn the process through which a forensic laboratory functions, from exhibits collected from crime scene through to a conclusion, is essential.
- For further information see the considerations of TWG Sub-Group B.

Recommendation 6: Maintain a dedicated and efficient information management capability for non-routine missions on a long-term basis.

- This should ensure that the necessary information is available at any point when needed, rather than trying to re-create such a capability after an investigation is mandated. Information management requires planning for continuing capability. Even when investigations are only conducted on an infrequent ad-hoc basis, there needs to be a continuing capability to manage information from past investigations, and to be prepared to manage information from any future investigations.
- Information from past non-routine missions should be available to those with a "need to know".
- For further information see the considerations of TWG Sub-Group B.

Recommendation 7: Manage information collected for investigative purposes separately from information related to routine verification activities.

- Given the sensitivity and stringent forensic requirements of an investigation, such information, which could lead to decisions by international policy-making organs (including the UN Security Council), or to national or international judicial action, should be completely separated from other verification – related information.
- For further information see the considerations of TWG Sub-Group B.

Recommendation 8: Design the information management structure to be hardware and software agnostic.

- Information management should be thought of in terms of the availability, usability, integrity and security of the data employed in an investigation. Information

management is not primarily a matter of hardware and software; people and processes are of key importance.
- For further information see the considerations of TWG Sub-Group B.

Recommendation 9: Partner with an international body in the UN system that maintains a similar information management capability for investigative information on a continuing long-term basis to gain access to existing tools and methodologies for information management.

- The Secretariat has created its own information management capabilities in response to its non-routine missions. These capabilities will need to be maintained and strengthened, and require periodic updates in software, hardware, and information management practices, which necessitates having adequate resources. Partnering with a well-resourced agency might be a way to minimise start-up time and cost if an investigation is mandated. A key issue would be ensuring that information is properly and appropriately protected.
- For further information see the considerations of TWG Sub-Groups B.

What are the best practices for the collection, handling, curation and storage, and annotation of evidence? *TOR sub-paragraph 4(d)*.

Recommendation 10: The Secretariat should ensure that forensic issues are included in R/SOPs and Working Instructions including those related to on-site sample collection, handling, curation and storage, and annotation in accordance with forensic best practices.[20]

- For investigations that may provide information suggesting a violation of the Convention, it is critical to ensure that the information used to draw any conclusion is able to meet internationally accepted standards. R/SOPs should be regularly reviewed and updated.
- For further information see the considerations of TWG Sub-Group D.

Recommendation 11: Identify and evaluate alternative means of collecting as much relevant information as possible about an incident site in advance of direct physical access, including the use of UAVs or commercial satellite imagery.

- This would help to maximise safety, security and effectiveness of on-site activity.
- This effort should include developing procedures and equipment through which non-OPCW personnel who have access can be used to collect and transfer information in a forensically sound manner.
- For further information see the considerations of TWG Sub-Group F.

Recommendation 12: For situations where OPCW personnel cannot access a sampling site, develop procedures and equipment for non-OPCW personnel to collect environmental or biomedical samples, and transfer them to OPCW.

- This would help to ensure integrity of samples and allow verification of authenticity of samples provided to the OPCW.
- Such procedures can make use of digital tools and technologies that are being developed and deployed for collection of verifiable information unaltered from its original form, substantiated by time stamps and geolocation data.
- For further information see the considerations of TWG Sub-Group F.

Which technologies and methodologies (whether established or new) allow point-of-care and non-destructive measurements at an investigation site to help guide evidence collection? *TOR sub-paragraph 4(e)*.

Recommendation 13: Enhance capabilities for the on-site detection of chemical warfare agents and related compounds, including newly scheduled agents, TICs, CNS-acting chemicals, and biological toxins, from a variety of environmental matrices, including gaseous, liquid and solid forms, to offer a broad coverage of possible scenarios.

- Fast and robust detection tools that can provide information at the point of measurement, or the point-of-need (e.g. analogous to a point-of-care use in a clinical setting) are needed for a broader range of scenarios. These would support an inspection team in collecting samples on-site, as well as enhancing its safety.
- The selection of detection equipment used for a mission should be based on available information and risk assessment in advance of deployment.
- For further information see the considerations of TWG Sub-Group C.

Recommendation 14: Continuously monitor and identify gaps in sampling and analysis capabilities for chemical threat agents, to enable the Secretariat to mitigate the consequences of those gaps.

- The Secretariat should draw upon established sources, expert communities, chemical industry and manufacturers of equipment to efficiently gain access to knowledge and capabilities. Areas of relevance include technologies for sampling, detection and analysis; automated and robotic systems; and for the analysis of inorganic compounds, TICs and CNS-acting chemicals.
- For further information see the considerations of TWG Sub-Group C.

Recommendation 15: Scenarios developed for mission planning and training should be adapted for the purpose of evaluating sampling and detection systems to meet mission conditions.[20]

- Where possible the Secretariat should seize opportunities to use scenario-based field exercises to evaluate available equipment to determine its fieldability to meet operational requirements. Evaluation of equipment could be an activity at OPCW's future Centre for Chemistry and Technology.[21] The Secretariat could also draw upon equipment evaluations available from Member States.
- For further information see the considerations of TWG Sub-Group C.

Recommendation 16: Work towards a greater degree of agility and flexibility regarding procurement of equipment by the Secretariat. A market watch function within the Secretariat to closely follow developments in relation to the operational needs would help to facilitate more efficient evaluation and procurement processes.

- For non-routine missions, this would allow the Secretariat to more rapidly adopt new technologies, which are especially important when considering the changing nature of threats and operational scenarios.
- For further information see the considerations of TWG Sub-Group C.

Recommendation 17: Ensure the Secretariat's analytical chemists and Designated Laboratories have access to procedures and analytical data needed for detection and identification of emerging chemical threat agents.

[21] For further information, see: Centre for Chemistry and Technology Project; www.opcw.org/media-centre/featured-topics/chemtech-centre.

- In addition to those of scheduled chemicals, add spectra, where available, of relevant unscheduled and newly scheduled chemicals to the OPCW Central Analytical Database (OCAD), for on-site and off-site identification purposes.
- Provide procedures for analysis of newly scheduled agents, TICs, CNS-acting chemicals and biological toxins.
- For further information see the considerations of TWG Sub-Group C.

Which technologies and methodologies (whether established or new) can be used in provenancing of chemical and/or material samples collected in an investigation? *TOR sub-paragraph 4(f)*.

Recommendation 18: Consider establishing a new TWG on the provenancing of samples of chemicals relevant to the Convention.

- Discussions should bring together SAB members, representatives of Designated Laboratories, and other experts in chemical forensics and profiling.
- Chemical profiling of samples to enable determination of their provenance requires analytical and data analysis approaches, and reference data that differ from those being currently employed by the Designated Laboratory Network for off-site verification analysis.
- The TWG would consider *inter alia* requirements for method development, and inter-laboratory chemical profiling exercises, standardisation and evaluation.
- For further information see the considerations of TWG Sub-Group E.

Recommendation 19: Develop a chemical profiling database.

- The OPCW Laboratory should consider developing an OPCW chemical profiling database for raw instrumental data (e.g. GC/MS data) for the composition of samples of chemical threat agents of known provenance, including but not limited to additives, synthetic impurities and degradation products.
- Previously collected data on chemical threat agent samples could be added to the database and used for testing approaches to chemical profiling.
- For further information see the considerations of TWG Sub-Group E.

Recommendation 20: Encourage the Secretariat and Designated Laboratory network to engage with, and where possible participate in projects of, the Chemical Forensics International Technical Working Group (CFITWG).

- The CFITWG is a forum for the development of peer-reviewed chemical profiling approaches and the exchange on information that is suited to the provenance determination on chemical warfare agents and related compounds, which is a developing field of science.
- For further information see the considerations of TWG Sub-Group E.

Recommendation 21: Publish scientific results obtained from the development of chemical profiling methods in peer-reviewed scientific literature.

- Peer-reviewed scientific publications demonstrate validity and robustness of methods and enable data comparison. They are viewed worldwide as important validations for investigative mechanisms.
- For further information see the considerations of TWG Sub-Group E.

Which methods are available (or are being developed) for the sampling and analysis of environmental and biomedical materials that can be used in the detection of toxic industrial chemicals relevant to the Convention? *TOR sub-paragraph 4(g)*.

Recommendation 22: Ensure that the Secretariat has access to capabilities for verification and response to threats from TICs.

- This would include defining and maintaining a prioritized TIC-list that includes the most likely types of chemicals for which capabilities might be required. Engaging with experts in biomonitoring and biomedical analysis methods for TICs, and with those handing and monitoring TICs in chemical industry would also help to ensure that the Secretariat is fully aware of state-of-the-art methods for sampling and analysis of TICs.
- For further information see the considerations of TWG Sub-Group C.

Which technologies and methodologies (whether established or new) can be used in ensuring chain of custody and verifying authenticity (especially in regard to digital images and video recordings)? *TOR sub-paragraph 4(h)*.

Recommendation 23: Consider how to best make use of suitable electronic evidence tracking technologies, which can be attached to, or packed with evidence/samples at the point of collection and followed electronically.

- Internet-of-things (IoT) devices that can record information on the handling and integrity of a packaged samples are an area to consider. Combinations of these tracking devices such as, Trace Identification Number [Spoor Identificatie Nummer (SIN)[22]], and the Comprehensive Test Ban Treaty/Onsite Inspection (CTBT/OSI) sample tracking system[23] can provide added capabilities for ensuring chain of custody. Distributed ledger technology (DLT/blockchain) should also be considered.
- For further information see the considerations of TWG Sub-Group D.

Which technologies and methodologies (whether established or new) can be used to ensure the integrity of an investigation site? *TOR sub-paragraph 4(i)*.

Recommendation 24: Make use of technologies that allow digitalised documentation of investigation scenes and sites. These technologies include UAVs and UGVs, photogrammetry and/or 3D scanning systems (which can be used individually or in combination).

- These technologies include UAVs and UGVs, photogrammetry and/or 3D scanning systems (which can be used individually or in combination). These tools and methods provide capabilities to provide real time images of an investigation site prior to entry and during a forensic investigation. Data collected in this manner would provide information on the risks present at the site prior to entry, guide the development of sampling strategies, and provide digitalised documentation of the incident site at the moment it was examined. The latter enables detailed examination of a scene to continue beyond the time an inspection team can be physically present, as well as providing benefits for chain-of-custody purposes.
- For further information see the considerations of TWG Sub-Group D.

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22 For additional information, see: https://polytrack.nl/.

23 See for example: "Several key COTS equipment's potential application to CTBTO OSI". X. He, X. Ge, P. Li; Abstract from CTBTO SnT2019; https://ctnw.ctbto.org/ctnw/abstract/32290.

Do collections of physical objects, samples, and other information for chemical weapons relevant analysis exist that can be made available to investigators for retrospective review? And how might these collections be used to support investigations? *TOR sub-paragraph 4(j)*.

Recommendation 25: Explore the possibilities for retrospective mining of previously collected data on authentic samples containing signatures of chemical threat agents.

- If permission can be obtained, such exercises would be useful for developing reference data that includes validated chemical signature information.
- For further information see the considerations of TWG Sub-Group E.

Recommendation 26: Encourage laboratories analysing authentic samples containing signatures of chemical threat agents to publish their results in peer-reviewed scientific journals, to enable additional validation of the methods and approaches, and to enhance overall the capability of the Designated Laboratory network.

- Reports of provenance determination on chemical warfare agent samples are especially relevant for validating the methods being developed in this developing field of science. They are also vital for providing standards against which any allegations of chemical weapons use in future can be compared, to increase the probability of finding concrete linkages between events in the past and those in the future. This is important for the identification of linkages between multiple events of alleged chemical weapon use.
- For further information see the considerations of TWG Sub-Group E.

Are there stakeholders that the Secretariat could usefully engage with, to leverage their capabilities on investigative matters? *TOR sub-paragraph 4(k)*.

Recommendation 27: Identify and liaise with forensic laboratories to build an informal network of providers for forensic services.

- The forensic laboratories should have ISO17025[24] or equivalent accreditation and proven and validated capabilities to answer mission-specific questions of the Secretariat.
- For further information see the considerations of TWG Sub-Group A.

Recommendation 28: Further strengthen engagement with scientific advisory mechanisms of other International Organisations that consider forensic issues.

- A number of international science advice mechanisms, particularly those in organisations with investigative responsibilities, maintain close ties with professional international forensic societies.
- It is important to engage with expert communities and to share experiences and best practices for technical advice. These interactions help to increase awareness of forensic options that can be useful to the Secretariat.
- Additionally, these networks provide opportunities to interact with a broad regional representation of forensic expertise.
- For further information see the considerations of TWG Sub-Group A.

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[24] ISO 17025: General requirements for the competence of testing and calibration laboratories; International Organization for Standardization, ISO/IEC 17025:2017; https://www.iso.org/standard/66912.html.

Recommendation 29: Establish working relationships with forensic science organisations, laboratories, and experts to ensure that the Secretariat has a network that can provide advice and analytical services at short notice.

- Given the diversity of analysis needs and technologies that may be required for non-routine operations, where high-end capabilities are needed on an infrequent basis, consideration could be given to accessing those capabilities through Service Level Agreements (SLA). Quality standards and/or accreditation requirements for the capability should be specified in the SLA.
- With regard to forensic expertise, the TWG on Investigative Science and Technology and the SAB have engaged with a broad range of international forensic expertise and organisations that the Secretariat may wish to contact. This can be facilitated through the SAB Secretary.
- For further information see the considerations of TWG Sub-Group A.

Recommendation 30: Consider establishing a TWG to advise on how to ensure that the Secretariat has access to required capabilities for the analysis of relevant biological toxins.

- Discussions should bring together SAB members, representatives of Designated Laboratories, and other experts in biological toxin analysis.
- Given the broad diversity of techniques required for toxin analysis, understanding the capabilities of a wider group of laboratories that perform analyses of toxins, in particular, High Molecular Weight (HMW) toxins, would be critical should toxin analysis be required for an investigation. An approach to overcoming capability limitations could be to rely on outside proficiency testing exercises to identify those laboratories experienced in the analysis of HMW toxins specifically, highly toxic protein toxins. Laboratories supporting the United Nations Secretary-General's Mechanism (UNSGM),[25,26] have experience with analysis of HMW toxins, and could, likewise, potentially seek laboratory and other support from OPCW Designated Laboratories that are proficient in analysis of low molecular weight (LMW) toxins.
- For further information see the considerations of TWG Sub-Group C.

Recommendation 31: Continue to strengthen working relationships with communities of expertise for identifying relevant open-source information and evaluating its authenticity, particularly for digital information.

- For further information see the considerations of TWG Sub-Group F.

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25 Secretary-General's Mechanism for Investigation of Alleged Use of Chemical and Biological Weapons;; https://www.un.org/disarmament/wmd/secretary-general-mechanism/.

26 For further information on the Swiss UNSGM Designated Laboratories Workshop series, see: https://www.labor-spiez.ch/en/rue/uno/index.htm. See also workshop reports: (a) UNSGM Designated Laboratories 5th Workshop Report, Spiez Laboratory, 2019; https://www.labor-spiez.ch/pdf/en/rue/UNSGM_Designated_Laboratories_5th_Workshop_Report.pdf (b) UNSGM Designated Laboratories 4th Workshop Report, Spiez Laboratory, 2018; https://www.laborspiez.ch/pdf/en/rue/UNSGM_Designates_Laboratories_4th_workshop_Report.pdf. (c) UNSGM Designated Laboratories 3rd Workshop Report, Spiez Laboratory, 2017; https://www.laborspiez.ch/pdf/en/rue/UNSGM_2017_FINAL_Report.pdf. (d) UNSGM Designated Laboratories 2nd Workshop Report, Spiez Laboratory, 2016; https://www.laborspiez.ch/pdf/en/rue/UNSGM_Def_Report_2016.pdf. (e) UNSGM Designated Laboratories 1st Workshop Report, Spiez Laboratory, 2015; https://www.laborspiez.ch/pdf/en/rue/UNSGM_Def_Report_2015.pdf. See also a fact-sheet on a Network of Nominated Biological Laboratories for the UNSGM; https://www.labor-spiez.ch/pdf/en/rue/Factsheet-Network_of_Nominated_Biological_Laboratories_for_the_UNSGM.pdf.

Recommendation 32: Make a concerted and continuing effort to engage current and former OPCW personnel who have participated in non-routine missions in improving the Secretariat's investigative capability.

- Involve these personnel in developing investigative procedures and equipment, and in the evaluation of training scenarios in preparation for future missions.
- Engage these personnel in identifying potential difficulties associated with the sustainability of non-routine missions and effective ways of addressing them. Attention should be paid to issues such as post-traumatic stress.
- For further information see the considerations of TWG Sub-Group F.

Additional advice on Secretariat's proposals for methodologies, procedures, technologies, and equipment for investigative purposes. *TOR paragraph 5.*

Recommendation 33: Strengthen the ability to evaluate and adopt new technologies and equipment to meet the Secretariat's evolving needs. Efforts can be put forth that involve both internal processes and voluntary assistance from Member States.

- Conduct a modest technology evaluation and adaptation programme, financed through the regular budget, to take advantage of equipment and procedures being developed in other contexts.
- Establish a programme for technical support conducted by Member States (this could follow the model of the IAEA).
- For further information see the considerations of TWG Sub-Group F.

Recommendation 34: Identify and carefully explore technical, forensic, and legal issues involved in providing technical investigative assistance to a State Party and inform Member States of the findings.

- Assisting a State Party may require different operating procedures than are used in investigations conducted by the OPCW.
- For further information see the considerations of TWG Sub-Group F.

Recommendation 35: Consider incorporation of end user requirements, such as reporting on technical information, into mission planning and operating procedures when conducting a mission that might transfer information to other entities.

- Information collected on-site by inspectors and/or generated through off-site analysis may potentially be transferred to others for further review. If the transferred information is to be subjected to further evaluation (in particular if it were to be reviewed under a legal framework which could require individuals involved in the investigation to justify their approaches), suitability of the methods and approaches to meet the needs of the evaluators must be considered.
- For further information see the considerations of TWG Sub-Group F.

Recommendation 36: Increase analytical capabilities for new chemical threat agents, in particular newly scheduled nerve agents.[16]

- More specifically, in order to:
    - detect such chemicals in the field, both to protect inspectors and to allow them to carry out verification or assistance activities and
    - to have reference standards and data for these chemicals, and their precursors and degradation products, in order to establish recommended analytical methods and to enable comparison of measurements and spectra.
- For further information, see the considerations of TWG Sub-Groups C and F.

Background

Formation and objectives of the Temporary Working Group on Investigative Science and Technology

Since a United Nations (UN)-led mission to the Syrian Arab Republic in 2013,[27] in which OPCW inspectors played a key role in investigating the use of chemical weapons, and the subsequent accession of the Syrian Arab Republic to the Convention, the OPCW's non-routine mission portfolio has continued to expand. This has seen the Secretariat verify removal of chemicals from the Syrian Arab Republic[1,3,28] and Libya[2] and their subsequent destruction outside the territories of these State Parties; initiate a Fact-Finding Mission (FFM) to determine credibility of allegations of use of chemical weapons;[4] establish a Declarations Assessment Team (DAT) to verify Syria's declarations;[29] implement a UN Security Council decision to carry out an OPCW-UN Joint Investigation Mechanism,[5] and participate in additional non-routine missions in the Syrian Arab Republic[8] which includes a 2016 decision by the Executive Council (hereinafter, "the Council") has required inspections at the Syrian Scientific Studies and Research Centre (SSRC),[30] Iraq,[9] Libya[31] and the United Kingdom.[10] A Rapid Response and Assistance Mission (RRAM)[32] has also been added to the Secretariat's assistance portfolio. Furthermore, an Investigation and Identification Team (IIT),[33] was

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27 (a) "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); https://undocs.org/A/68/663.

28 (a) UN to investigate allegations of the use of chemical weapons in the Syrian Arab Republic Fact Sheet, UNODA, 2017; https://s3.amazonaws.com/unoda-web/wp-content/uploads/2017/07/Syrian-CW-Investigation-Fact-Sheet-Jul2017.pdf. (b) "Lessons Learned from the OPCW Mission in Syria", R. Trapp, www.opcw.org/sites/default/files/documents/PDF/Lessons_learned_from_the_OPCW_Mission_in_Syria.pdf.

29 For further information on the Declaration Assessment Team, see: www.opcw.org/declarationassessment-team.

30 (a) "Status of Implementation of Executive Council Decision EC-83/DEC.5 (dated 11 November 2016)" (EC-87/DG.15, dated 23 February 2018; and EC-87/DG.15/Add.1, dated 28 February 2018), (b) "First Inspections at the Barzah and Jamrayah Syrian Scientific Studies and Research Centre Facilities in Syrian Arab Republic in Accordance with Decision EC-83/DEC.5 (dated 11 November 2016)", (EC-85/DG.16, dated 2 June 2017), and (c) "Report by the Director-General: Status of Implementation of Executive Council Decision EC-83/DEC.5 (dated 11 November 2016)" (EC-84/DG.25, dated 6 March 2017): www.opcw.org/sites/default/files/documents/EC/84/en/ec84dg25_e_.pdf.

31 (a) "Results of samples associated with the Technical Secretariat's evaluation of the amended declaration submitted by Libya with regard to the Category 2 chemical weapons stored at the Ruwagha chemical weapons storage facility" (EC-89/S/3, dated 2 October 2018 (b) "Technical Secretariat's Evaluation of the Amended Declaration Submitted by Libya with Regard to the Category 2 Chemical Weapons Stored at the Ruwagha Chemical Weapons Storage Facility" (EC-83/S/2, dated 12 August 2016).

32 (a) "Note by the Technical Secretariat: Establishment of a Rapid Response Assistance Team" (S/1381/2016, dated 10 May 2016): www.opcw.org/sites/default/files/documents/S_series/2016/en/s1381-2016_e_.pdf and, (b) "Note by the Technical Secretariat: Guidelines for States Parties Requesting a Rapid Response and Assistance Mission" (S/1429/2016, dated 17 October 2016): www.opcw.org/sites/default/files/documents/S_series/2016/en/s-1429-2016_e_.pdf.

33 For recent updates, see: (a) "Report by the Director-General: Progress in the Implementation of Decision C-SS-4/DEC.3 on Addressing the Threat from Chemical Weapons Use" (EC-91/DG.20, dated 1 July 2019): www.opcw.org/sites/default/files/documents/2019/07/ec91dg20%28e%29.pdf. (b) Work of the Investigation and Identification Team Established by Decision C-SS-4/DEC.3 (Dated 27 June 2018) (EC-91/S/3, dated 28 June 2019). And, (c) "Report by the Director-General: Progress in the Implementation of Decision C-SS-4/DEC.3 on Addressing the Threat from Chemical Weapons Use" (EC-90/DG.14, dated 7 March 2019):

established following a decision by States Parties in June 2018 to address the use of chemical weapons in the Syrian Arab Republic, including the identification of perpetrators. The 2018 decision also mandated the Director-General to provide technical assistance to a member state investigating the possible use of chemical weapons on its own territory, which could involve the use of toxic chemicals by Non-State Actors.[34] The non-routine missions demonstrate scenarios and situations previously thought unlikely, and that do not fall under the provisions for investigations of alleged use (IAUs) or challenge inspections (CIs) under Articles IX and X of the Convention,[35] yet their objectives can contain similar aspects.

Non-routine missions present a range of new and unexpected challenges, particularly with regard to access to reliable information to guide mission planning, scene assessment and conduct of operations. Available information on a chemical incident, as well as situational awareness for safe assessment of the scene can be affected by factors that are difficult to evaluate. For example, the team may need to assess witness statements and materials provided by external parties which were collected outside the supervision of an inspection team. The information that might need to be considered could include allegations of casualties, reported observations of symptoms, social media posts, digital images and videos, and a variety of open source materials.

Additionally, OPCW's non-routine missions often take place in non-permissive environments, where inspectors face delayed access, limited time on site and/or equipment constraints. Under these circumstances, operating procedures designed for permissive environments may be unsuitable. These operating conditions can complicate identification of potential hazards, which can compromise the capability to mitigate operational dangers and limit the ability to perform targeted collection of the most suitable samples and evidence for further analysis. OPCW non-routine missions have been undertaken in hostile environments, in extreme weather conditions, and under dynamic security situations.[36]

Recognising where modern investigative techniques can deliver valuable and actionable information, the SAB recommended at its Twenty-Fourth Session, the establishment of a TWG to conduct an in-depth review of methods and technologies that could be used by OPCW for investigative work.[37] The SAB reasoned that capabilities enabled through advances in investigative science and technology would benefit the robustness of information and analysis associated with non-routine missions. Key inputs for this recommendation came through findings of a previous TWG on verification[38] and two international workshops

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www.opcw.org/sites/default/files/documents/2019/03/ec90dg14%28e%29.pdf. For further information see: www.opcw.org/media-centre/featured-topics/decision-addressing-threat-chemical-weapons-use.

34 "Decision: Addressing the Threat Posed by the Use of Chemical Weapons by Non-State Actors", EC-86/DEC.9, dated 13 October 2017; www.opcw.org/sites/default/files/documents/EC/86/en/ec86dec09_e_.pdf.

35 "Three Types of Inspections", OPCW Fact Sheet Number 5 (2017); www.opcw.org/sites/default/files/documents/Fact_Sheets/English/Fact_Sheet_5_-_Inspections.pdf.

36 See (a) paragraphs 5.3 to 5.5 of "Report of the Scientific Advisory Board's Workshop on Emerging Technologies" (SAB-26/WP.1, dated 21 July 2017); www.opcw.org/sites/default/files/documents/SAB/en/sab26wp01_SAB.pdf. (b) Paragraphs 8.1 to 8.3 of SAB-27/WP.1 (referenced in footnote 12).

37 See paragraphs 1.2 and 8.12 to 8.17 of the Report of the Scientific Advisory Board at its Twenty Fourth Session (SAB-24/1, dated 28 October 2016); www.opcw.org/sites/default/files/documents/SAB/en/sab-24-01_e_.pdf.

38 "Verification Report of the Scientific Advisory Board's Temporary Working Group" (SAB/REP/1/15, dated 11 June 2015). www.opcw.org/sites/default/files/documents/SAB/en/Final_Report_of_SAB_TWG_on_Verification_-_as_presented_to_SAB.pdf.

organised by the SAB in 2016 and 2017 on chemical forensics[39] and emerging technologies.[40] The SAB's advice to the Fourth Review Conference of the Chemical Weapons Convention,[41] emphasised the need for the Secretariat to build upon its existing investigative science capabilities in order to maintain and expand its effectiveness to meet future challenges.[42]

At the request of the Director-General, the TWG on Investigative Science and Technology was established in 2017.[11] Dr Veronica Borrett of the SAB, was appointed as the TWG Chairperson with support from Vice-Chairperson Dr Ed van Zalen. The TWG's programme of work was to review science and technology relevant to investigations such as those mandated under Articles IX and X of the Chemical Weapons Convention. This would include science and technology for the validation and provenancing (i.e. determining the chronology of ownership, custody and/or location) of evidence, and the integration of multiple and diverse inputs to reconstruct a past event. Additionally, the TWG was asked to undertake further consideration of recommendations from the SAB's 2016 chemical forensics workshop and assessment of relevant scientific and technological merits of methodologies, emerging technologies and new equipment which could be used in OPCW verification activities.[43] These topics have significant relevance to the Convention's verification regime, especially for sampling and analysis, and collection and validation of information in support of non-routine missions. The terms of reference (TOR) of the TWG are provided in Annex 1 of this report.

The TWG held five meetings from February 2018 to November 2019, with a combined attendance of nearly 150 people from 36 States Parties.[13] Through these meetings, the TWG received more than 100 briefings from the Secretariat and invited experts. The Secretariat provided insight into its non-routine mission portfolio from current and former inspectors. These briefings provided important insights and lessons learned from the field regarding equipment and procedures that could help strengthen its investigative capabilities. This expertise included forensic intelligence; methods for detecting concealment or tampering of digital information; remote sampling using unmanned ground and aerial vehicle platforms, and the use of satellite imagery for retrospective analysis and proactive monitoring; chemical and biomarker analysis, including methods for identifying chemical exposure induced injury; investigations of recent high-profile cases involving chemical agents including toxins, international arms control, disarmament and non-proliferation treaty verification; the collection of evidence and information under adverse circumstances; and the use of open source intelligence for verification applications. Lists of the TWG members and the guest speakers who helped inform their deliberations are provided in Annexes 3 and 4 of this report.

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39 "Report of the Scientific Advisory Board's Workshop on Chemical Forensics" (SAB-24/WP.1, dated 14 July 2016). www.opcw.org/sites/default/files/documents/SAB/en/sab24wp01_e_.pdf.

40 "Report of the Scientific Advisory Board's Workshop on Emerging Technologies" (SAB-26/WP.1, dated 21 July 2017); www.opcw.org/sites/default/files/documents/SAB/en/sab26wp01_SAB.pdf

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

42 "Report of the Scientific Advisory Board on Developments in Science and Technology for the Fourth Special Session of the Conference of the States Parties to Review the Operation of the Chemical Weapons Convention" (RC-4/DG.1, dated 30 April 2018): www.opcw.org/sites/default/files/documents/CSP/RC4/en/rc4dg01_e_.pdf. An executive summary brochure is also available; www.opcw.org/sites/default/files/documents/2018/10/SAB_RC4-Executive_Summary_Recommendations_-_web.pdf.

43 Chemical Weapons Convention Article VIII, paragraph 6; www.opcw.org/chemical-weapons-convention/articles/article-viii-organization.

An important and valuable aspect across the meetings was the engagement between the TWG and Secretariat's management and staff, especially those with field experience, as well as external forensic practitioners. This ensured that the operational context was well understood by the TWG and provided opportunities for the Secretariat to learn from the technical briefings and discussions. This should help pave the way for the seamless integration of any recommendations that are adopted by the OPCW.

Findings of the Temporary Working Group on Investigative Science and Technology

Given the broad scope of thematic topics in the terms of reference (see paragraphs 4 and 5 of the TOR in Annex 1), six sub-groups (A, B, C, D, E and F) were established to take forward the programme of work. The questions that the TWG was asked to address were grouped into six sets of related thematic topics and each set assigned to one sub-group as indicated in Table 1. This summary of findings is organised according to the work of each sub-group.

Table 1: Sub-Groups of the TWG and their areas of consideration.

Sub-Group	Questions Considered from the Terms of Reference (TOR)
A	TOR Sub-Paragraph 4(a): Which methods and capabilities used in the forensic sciences could usefully be developed and/or adopted for Chemical Weapons Convention-based investigations? TOR Sub-Paragraph 4(k): Are there stakeholders that the Secretariat could usefully engage with to leverage their capabilities on investigative matters?
B	TOR Sub-Paragraph 4(b): What are the best practices and analysis tools used in the forensic sciences for effectively cross-referencing, validating, and linking together information related to investigation sites, materials collected/analysed and individuals interviewed? TOR Sub-Paragraph 4(c): What are the best practices for management of data collected in investigations, including compilation, curation, and analytics?
C	TOR Sub-Paragraph 4(e): Which technologies and methodologies (whether established or new) allow point-of-care and non-destructive measurements at an investigation site to help guide evidence collection? TOR Sub-Paragraph 4(g): Which methods are available (or are being developed) for the sampling and analysis of environmental and biomedical materials and can be used in the detection of toxic industrial chemicals relevant to the Convention?
D	TOR Sub-Paragraph 4(d): What are the best practices for the collection, handling, curation and storage, and annotation of evidence? TOR Sub-Paragraph (4h): Which technologies and methodologies (whether established or new) can be used in ensuring chain of custody and verifying authenticity (especially in regard to digital images and video recordings)? TOR Sub-Paragraph 4(i): Which technologies and methodologies (whether established or new) can be used to ensure the integrity of an investigation site?
E	TOR Sub-Paragraph 4(f): Which technologies and methodologies (whether established or new) can be used in provenancing of chemical and/or material samples collected in an investigation? TOR Sub-Paragraph 4(j): Do collections of physical objects, samples, and other information for chemical weapons-related analysis exist and can they be made available to investigators for retrospective review? How might these collections be used to support investigations?
F	Additional advice, including TOR Sub-Paragraph 5: advice on the Secretariat's proposals for methodologies, procedures, technologies, and equipment for investigative purposes.

Sub-group A: Forensic Methods and Capabilities

Sub-group A was tasked to address forensic methods and capabilities, with focus on the questions from sub-paragraphs 4(a) and 4(k) of the TWG's TOR, which are:

- Which methods and capabilities used in the forensic sciences could usefully be developed and/or adopted for Chemical Weapons Convention-based investigations?

- Are there stakeholders that the Secretariat could usefully engage with to leverage their capabilities on investigative matters?

The sub-group looked at three priority areas to address the assigned questions:

- Exploration of the range of available forensic resources and their accessibility;

- Consideration of opportunities to involve Designated Laboratories and forensic laboratories to explore areas of common interest; and,

- Engagement with forensic science networks, building on existing relationships.

Forensic science encompasses the study of traces (remnants of presence and/or activity),[44] where the traces serve as silent witnesses that need to be detected and understood to make reasonable inferences about criminal phenomena, investigation or demonstration for intelligence, investigation and court purposes. This requires that a spectrum of techniques and methods be available to allow the use of multiple types of data streams to draw conclusions about the circumstances surrounding an event of interest. Of relevance to the work of the Secretariat, is how chemical information is integrated with other measurements and evidence for identification purposes.

The integration of different data types and the linkages they reveal is most effectively performed through a forensic intelligence approach. Forensic intelligence is not solely limited to investigations or to confirm hypotheses suggested by conventional investigative means, but also to proactively provide insights into activities of those who plan and execute a chemical incident and to support the elicitation of relevant hypotheses.

To complement the Secretariat's expertise in chemical analysis and from consideration of the types of data collected in non-routine missions, the following inventory of forensic capabilities were highlighted as being relevant:

- Digital technologies: image analysis (e.g. authentication, meta-data, correlation of images), analysis of digital files[45] (authentication, destruction, concealment,

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44 *The Routledge International Handbook of Forensic Intelligence and Criminology;* Q. Rossy, D. Decary-Hetu, O. Delemont, M. Mulone (eds), Routledge, London, 2017. DOI: 10.4324/9781315541945.

45 (a) "Digital transformation risk management in forensic science laboratories". E. Casey, T. Souvignet; Preprint submitted to *FSI Digital Investigations*, January 2020. (b) *A Framework for Harmonizing Forensic Science Practices and Digital/Multimedia Evidence*; OSAC Technical Series 0002, OSAC Task Group on Digital/Multimedia Science; 2018; https://www.nist.gov/sites/default/files/documents/2018/01/10/osac_ts_0002.pdf (c) *Digital Evidence & Computer Crime: Forensic Science, Computers and the Internet*; E. Casey; Academic Press; 2011. (d) Reconstructing Digital Evidence; E. Casey in Crime Reconstruction; W. J. Chisum, B. Turvey;

tampering), analysis of social media (sources, trends), document analysis, Big Data analysis, site documentation (e.g. 3D image generation and digitalisation[46]).

- Biometrics: facial recognition, fingerprint analysis, speech analysis (including voice analysis from radio communications and video clips), handwriting analysis, and DNA analysis.[47]

- Explosions, explosives and munitions: impact analysis, identification and profiling, and ballistics.

- Forensic medicine and forensic toxicology: autopsy (which requires a medical doctor, and consideration of performing on or near the location of the incident, as well as any cultural or religious considerations), analysis of human tissues and body fluids and interpretation related to the cause of death or injury.[48]

Existing capabilities in chemical analysis, especially chemical profiling methods based on intrinsic (isotopes and stereoisomers) and extrinsic signatures (impurity profiling) for organic and inorganic chemicals should be augmented with expertise in chemical forensics, materials characterisation, and chemical engineering.

Critical for any investigation team is an impartial forensic adviser. The adviser should have a broad background in forensic analysis and for chemical weapon related investigations, requires familiarity with chemical weapons issues, knowledge of applicable (inter)national laws, and knowledge of networks of forensic laboratories as well as the Designated Laboratories. A pool of forensic advisers could also be considered.

Operationally, forensic advisers provide advice for the selection of exhibits to be examined in relation to the incident of interest and investigative questions, guide the phrasing of forensic questions and explain the outcome of the forensic analysis. An individual in this role must possess strong communication skills.

Academic Press, 2011, Chapter 17, 531-548. DOI: 10.1016/B978-0-12-386460-4.00017-5. (e) The growing impact of full disk encryption on digital forensics; E. Casey, G. Fellows, M. Geiger, G. Stellatos; Digital Investigation; 2011, 8(2), 129-134. DOI: 10.1016/j.diin.2011.09.005.

46 "Imaging in forensic science: five years". R. M. Carew, D. Errickson; J. Forensic Rad. Imaging, 2019, 16, 24-33. DOI: 10.1016/j.jofri.2019.01.002. (b) See also paragraphs 11.1 to 11.2 of SAB-29/WP.01 (referenced in footnote 13(d)).

47 M. Tistarelli, E. Grosso, D. Meuwly; "Biometrics in Forensic Science: Challenges, Lessons and New Technologies"; In: V. Cantoni, D. Dimov, M. Tistarelli (eds), Biometric Authentication. BIOMET 2014. Lecture Notes in Computer Science, 2014, 8897. Springer, Cham. DOI: 10.1007/978-3-319-13386-7_12.
(a) D. Seckiner, X. Mallett, P. Maynard, D. Meuwly, C. Roux; "Forensic gait analysis - Morphometric assessment from surveillance footage"; *Forensic Sci. Int.*; 2019, *296*, 57-66. DOI: 10.1016/j.forsciint.2019.01.00. (b) C. G. Zeinstra, D. Meuwly, A. C. Ruifrok, R. N. Veldhuis, L. J. Spreeuwers; "Forensic face recognition as a means to determine strength of evidence: A survey"; *Forensic Sci. Rev.*; 2018, *30(1)*, 21-32. (c) A. J. Leegwater, D. Meuwly, M. Sjerps, P. Vergeer, I. Alberink; "Performance Study of a Score-based Likelihood Ratio System for Forensic Fingermark Comparison"; *J. Forensic Sci.*; 2017, *62(3)*, 626-640. DOI: 10.1111/1556-4029.13339. (d) D. Maltoni, R. Cappelli, D. Meuwly; "Automated Fingerprint Identification Systems: From Fingerprints to Fingermarks"; in: M. Tistarelli, C. Champod C. (eds); *Handbook of Biometrics for Forensic Science. Advances in Computer Vision and Pattern Recognition*, 2017 Springer, Cham. DOI: 10.1007/978-3-319-50673-9_3.

48 For example: (a) H. John, M. J. van der Schans, M. Koller, H. E. T. Spruit, F. Worek, H. Thiermann, D. Noort; "Fatal sarin poisoning in Syria 2013: forensic verification within an international laboratory network"; *Forensic Toxicology*, 2018, *36(1)*, 61–71. DOI: 10.1007/s11419-017-0376-7. (b) Paragraphs 8.2 to 8.3 of SAB-24/WP.1 (references in footnote 39).

Given the broad variety of forensic analysis capabilities that might be required, the Secretariat would benefit from access to laboratories capable of performing a range of forensic analyses in addition to the current analysis capabilities of the Designated Laboratories. Considerations in identifying suitable laboratories include: ISO 17025 accreditation, participation in relevant proficiency testing (which should be broader than chemical identification, and include examination of exhibits, interpretation and drawing conclusions), and the capability to handle (possible) contaminated evidence. Laboratories should have capabilities matched to investigative needs, be able to maintain chain of custody and confidentiality, and be capable of bringing information into a legal framework.

There is also a need for identifying laboratories with geographic diversity and establishing memorandums of understanding, SLAs, or other suitable relationships. The roles of government ministries, delegations and National Authorities in the working relationships with any potential partner laboratory should also be considered, as political considerations must be taken into account. Agreements with suitable laboratories should be pursued to allow a selection of them to be called upon when needed. Such laboratory relationships would require working procedures be developed.

Finally, the sub-group reviewed investigative workflows and how these might look in the context of the OPCW, indicating points along the workflow where an impartial forensic adviser would be beneficial and the development of an impartial review process. For each of the investigation phases (Figure 1), and especially for crime scene investigation (CSI), R/SOPs, applications and technologies need to be identified and selected for implementation. It is important to adjust and integrate R/SOPs into the existing workflows of an organisation. An impartial forensic advisor is a resource across the different phases of the investigation to advise on the questions asked, selection of the exhibits to be examined, and reporting the results of the laboratory investigations. At the end of the investigative process, integrated reports, where the results of the investigations are evaluated on whether or not they support the narrative of the incident, including any conclusions that have been determined, are useful for communicating the findings.

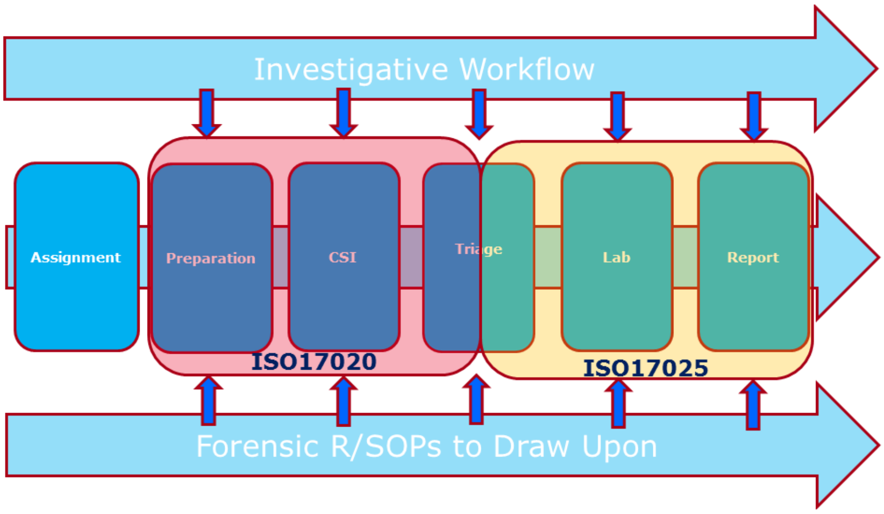

Figure 1: Forensic workflow.

<u>Recommendations of Sub-group A</u>

Recommendation: *Appoint a forensic advisor with broad experience in forensic science, forensic examinations and international law to provide advice to the Director-General and the OPCW.*[20]

An independent external expert could be considered. When undertaking investigations, inspection teams would benefit from having a forensic adviser available for consultancy to provide forensic advice off-site, for optimal planning and conduct of investigative activities to ensure they meet international forensic standards, take advantage of modern forensic methods, and incorporate the broad range of available forensic expertise.

Recommendation: *Create ownership by engaging the Secretariat in the integration of forensic R/SOPs into the OPCW workflows*.

A working group of Secretariat staff and forensic experts could be established to integrate forensic practices into relevant R/SOPs, and applications and technologies into the OPCW workflows for non-routine missions. This working group could also advise on Secretariat training curriculum.

Recommendation: *Ensure that the technical findings of an investigation undergo an objective review consistent with forensic best practice to provide the Director-General with an additional level of quality assurance.*

Reviewers could be engaged by the OPCW on an anonymous basis and be appointed from external organisations. They would have recognised expertise in technical fields and/or forensic science relevant to the specific investigation.

Recommendation: *Identify and liaise with forensic laboratories to build an informal network of providers for forensic services.*

The forensic laboratories should have ISO17025[24] or equivalent accreditation and proven and validated capabilities to answer mission-specific questions of the Secretariat.

Recommendation: *Establish working relationships in advance with forensic science organisations, laboratories, and experts to ensure that the Secretariat has a network that can provide advice and analytical services on short notice.*

With regard to laboratories, given the diversity of analysis needs that are plausible in non-routine operations, where high-end capabilities are required on an infrequent basis, consideration could be given to accessing those capabilities through SLA. Quality standards and/or accreditation requirements for the capability should be specified in the SLA. With regard to forensic expertise, the TWG on Investigative Science and Technology, and the SAB have engaged with a broad range of international forensic expertise and organisations that the Secretariat may wish to contact. This can be facilitated through the SAB Secretary.

Recommendation: *Further strengthen engagement with scientific advisory mechanisms of other International Organisations that consider forensic issues.*

These interactions will help to increase awareness of forensic options that can be useful to the Secretariat. A number of international science advice mechanisms, particularly those in organisations with investigative responsibilities, maintain close ties with professional international forensic societies. It is important to engage with expert communities and to share experiences and best practices for technical advice. Additionally, these networks provide opportunities to interact with a broad regional representation of forensic expertise.

Sub-group B: Data Collection and Management

Sub-group B was tasked to address data collection and management, with focus on the questions from sub-paragraphs 4(b) and 4(c) of the TWG's TOR, which are:

- What are the best practices and analysis tools used in the forensic sciences for effectively cross-referencing, validating, and linking together information related to investigation sites, materials collected/analysed and individuals interviewed?

- What are the best practices for management of data collected in investigations, including compilation, curation, and analytics?

The sub-group looked at two priority areas to address the assigned questions:

- Exploration of chain-of-custody best practices and technologies that are in use; and,

- Exploration of best practices for data management (including data analytics) and how these can be applied while maintaining appropriate confidentiality.

Elements of best practices for forensic data collection and management were identified within documents produced by forensic institutes, International Organizations, the International Criminal Court (ICC), International Standards Organizations (ISO) and a number of Academic Institutes. None of the documents the TWG reviewed were themselves stand-alone R/SOPs on data collection and management, indicating the necessary procedures for a given type of data may need to be specifically included within relevant R/SOPs. This would ideally be achieved in consultation with a forensic expert experienced in chemical warfare agent related investigations.

An important aspect of data collection that must be considered is that the mandate of the mission will dictate the manner in which a forensic investigation is conducted.[49] There may also be multiple organisations looking at a specific incident (or series of incidents) with different focus areas, for example genocide, crimes against humanity, use of chemical weapons, or gender based violence, with each mission collecting information independently of one another. This requires a fit for purpose information management system.

Ultimately, any information management system needs to allow case investigators access to relevant data streams and analysis tools to evaluate linkages and relationships for a case of interest. Systems such as the NFI Hansken[50] provide useful examples for balancing security,

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49 See paragraphs 11.1 to 11.6 of SAB-28/WP.3 (referenced in footnote 13(c)).

50 For further information on Hansken, see https://www.forensicinstitute.nl/products-and-services/forensic-products/hansken.

privacy and transparency in ways that allows a platform to be used across agencies and across forensic disciplines. How the data management system is configured for use will depend on the needs of the organisation(s) involved and investigation. The system can be set up to allow searching across cases that may not necessarily be related or can be set up to limit access to individual cases in isolation from others. Furthermore, effective use of such tools requires access to information management and digital forensics expertise to provide guidance to investigators.

Information management capabilities developed for specific OPCW missions should be approached in a manner that ensures there is no loss of capability in future. Appropriate planning to address this issue should be prioritised and information management considered in a systematic way. In this regard, there may be value in exploring and drawing on capabilities from other international organizations to ensure continuing capability.

In regard to the preservation of evidence, evidence must be preserved (to the greatest extent possible) in the same state as it was received. From the evidence replication/reproduction of analyses either internally or externally must also be possible. However, this cannot always be achieved as destructive analytical techniques may be required. In a traditional forensic science laboratory, this would require a waiver signed by the stakeholder. Evidence can degrade through natural processes, especially with chemical samples in complex matrices.[51] Another complication recognised by the TWG is that in chemical weapon demilitarisation missions, samples have not been retained, making retrospective analysis impossible.

Any given type of evidence will also require specific procedures unique to that type of evidence. For example, in standard forensic science procedures involving the collection of samples for DNA analysis, anonymized reference samples of all team members must also be taken and included with the samples.[52]

When following any R/SOP for evidence collection and analysis that may go into a regulatory or legal environment, adherence to procedures described in the document (and being able to identify the exact version of the document employed) is important, should a court require them later.

Chain of custody is defined as the uninterrupted control of evidence from the scene of an incident to a court. This is also known as: Care and Control of Evidence; Continuity of Possession and Exhibit Continuity. Following strict forensic procedures, evidential material is handled at every step as if it is to be presented in a courtroom; this requires documentation showing the chronology of custody, control, transfer, receipt or relinquishment of items/exhibits. Furthermore, the number of individuals handling the evidence is best limited

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51 (a) "Response to the Director-General's Request to the Scientific Advisory Board to Provide Further Advice on Chemical Weapons Sample Stability and Storage" (SAB-23/WP.2, dated 25 May 2016); www.opcw.org/sites/default/files/documents/SAB/en/sab-23-wp02_e_.pdf. (b) "Advice on Chemical Weapons Sample Stability and Storage Provided by the Scientific Advisory Board of the Organisation for the Prohibition of Chemical Weapons to Increase Investigative Capabilities Worldwide, C. M. Timperley, J. E. Forman, M. Abdollahi, A.S. Al-Amri, I. P. Alonso, A. Baulig, V. Borrett, F. A. Cariño, C. Curty, D. González Berrutti, Z. Kovarik, R. Martínez-Álvarez, R. Mikulak, N. M. Fusaro Mourão, P. Ramasami, S. Neffe, S. K. Raza, V. Rubaylo, K. Takeuchi, C. Tang, F. Trifirò, F. Mauritz van Straten, P. S. Vanninen, V. Zaitsev, F. Waqar, M. Saïd Zina, M.-M. Blum, H. Gregg, E. Fischer, S. Sun, P. Yang; *Talanta*; 2018, *188*, 808-832. DOI: 10.1016/j.talanta.2018.04.022.

52 See for example DNA related forensic guidelines and best practices made available through the European Network of Forensic Science Institutes; http://enfsi.eu/documents/.

to the smallest number possible, with each transfer properly documented to maintain the chain of custody. In a courtroom, the prosecution has a duty to prove the integrity of an exhibit, and more specifically to demonstrate that the exhibit from where the sample was taken is the same as that collected at the scene of the incident.

If information collected in an investigation is intended to go beyond the scientists doing the analysis, it is important to consider that the case files are disclosable. This requires that a case report be prepared which includes findings, interpretations and conclusions. This report would be a complete document and must include enough information to be reviewed by another expert. This forensic report might ultimately form part of a legal dossier and the reporting officer may be called upon to testify in a judicial process. Additionally, anyone from an organisation involved in analysis of material collected in an investigation may be called upon to testify about analyses, interpretations and conclusions, forensic significance, evidence handling and chain of custody, policies and procedures. The files must identify everyone who was involved; any of them might be summoned to testify. This includes scientists, analysts, managers and support staff of the institution; this may require additional training to prepare for such an eventuality.

The case report would include a diversity of evidence and information, including: case reports and notes; analytical results and interpretation; quality control and chain of custody information; images; evidential material descriptions; phone logs; witness interviews; the curriculum vitae of scientists involved in an analysis; proficiency test records; and, performance and training records. This is often referred to as a forensic case file, which is the end result for presentation in a courtroom.

Establishing a sound forensic case file requires that R/SOPs are aligned to meeting the mandate of the end user, in this case the Secretariat. In this regard, R/SOPs that are relevant to investigative work would benefit from review by forensic experts to ensure that they are fit for purpose, especially if the evidence collected will ultimately go into a judicial environment. An R/SOP review in this context would be to ascertain whether procedures used to obtain evidence, images, interviews and other information are suitable for building a forensic case file. The TWG recognises the importance of reviewing R/SOPs by recognised experts to ensure they are forensically robust.

In regard to TOR sub-paragraph 4(c), it would be useful for inspectors involved in investigative work to visit forensic institutes and receive training on forensic methods. Additionally, this would provide the inspectors with an overview on how a case is handled from beginning to end. The value of such an exercise is that even if a non-routine mission is not charged with identification of those involved, on-site inspectors are still effectively performing a scene of incident investigation, which forms the foundation of any further work toward identification of perpetrators. Having inspectors observe the process through which a forensic laboratory moves from collection of exhibits to a courtroom would provide a holistic view and understanding of a forensic process.

Recommendations of Sub-group B:

Recommendation: *Review existing relevant R/SOPs together with an expert forensic consultant to ensure that they are forensically sound and fit for purpose, suitable for inclusion in a forensic case file and able to meet the requirements of the end user.*

> Effectively cross-referencing the information collected across an investigation is best accomplished through the establishment of a forensic case file containing all

components, including R/SOPs aligned to meeting the mandate of the end user. OPCW R/SOPs used to obtain evidence, images, interviews and other information must be forensically sound and suitable to build a forensic case file.

Recommendation: *Ensure that Secretariat staff tasked with either reviewing or creating R/SOPs for forensic investigations understand forensic case management systems.*

An inspection team working in an investigative capacity in response to an alleged incident, is effectively undertaking a forensic investigation. Having inspectors learn the process through which a forensic laboratory functions, from exhibits collected from crime scene through to a conclusion, is essential.

Recommendation: *Maintain a dedicated and efficient information management capability for non-routine missions on a long-term basis.*

This should ensure that the necessary information is available at any point when needed, rather than trying to re-create such a capability after an investigation is mandated. Information management requires planning for continuing capability. Even when investigations are only conducted on an infrequent ad-hoc basis, there needs to be a continuing capability to manage information from past investigations, and to be prepared to manage information from any future investigations. Information from past non-routine missions should be available to those with a "need to know".

Recommendation: *Manage information collected for investigative purposes separately from information related to routine verification activities.*

Given the sensitivity and stringent forensic requirements of an investigation, such information, which could lead to decisions by international policy-making organs (including the UN Security Council), or to national or international judicial action, should be completely separated from other verification related information.

Recommendation: *Design the information management structure to be hardware and software agnostic.*

Information management should be thought of in terms of the availability, usability, integrity and security of the data employed in an investigation. Information management is not primarily a matter of hardware and software; people and processes are of key importance.

Recommendation: *Partner with an international body in the UN system that maintains a similar information management capability for investigative information on a continuing long-term basis to gain access to existing tools and methodologies for information management.*

The Secretariat has created its own information management capabilities in response to its non-routine missions. These capabilities will need to be maintained and strengthened, and require periodic updates in software, hardware, and information management practices, which necessitate having adequate resources. Partnering with a well-resourced agency might be a way to minimize start-up time and cost if an investigation is mandated. A key issue would be ensuring that information is properly and appropriately protected.

Sub-group C: Sampling, Detection and Analysis

Sub-group C was tasked to address detection and analysis, with focus on the questions from sub-paragraphs 4(e) and 4(g) of the TWG's TOR, which are:

- Which technologies and methodologies (whether established or new) allow point-of-need and non-destructive measurements at an investigation site to help guide evidence collection?

- Which methods are available (or are being developed) for the sampling and analysis of environmental and biomedical materials and can be used in the detection of toxic industrial chemicals relevant to the Convention?

The sub-group looked at four priority areas to address the assigned questions:

- Exploration of available tools for specific categories of chemicals of relevance (not limited to scheduled chemicals);

- Exploration of inputs from industry, first responders and environmental monitoring on the tools and approaches that may be available (this could be especially relevant for toxic industrial chemicals);

- For detection of toxic industrial chemicals in biomedical samples, gathering published materials about environmental and occupational exposure (including some older science) is relevant. Engagement with forensic toxicologists can also be explored; and,

- Consider available remote monitoring and/or portable systems, including consideration of evaluation reports of available technologies.

On-site measurements would ideally permit the detection of chemical warfare agents and related compounds in gaseous, liquid and solid forms, as well as toxic materials of biological origin (toxins). To offer a more complete coverage of possible chemical incident scenarios, newly scheduled agents, TICs, and CNS-acting chemicals, such as fentanyls, should also be considered. Measurements could be based on physical, chemical or enzymatic technologies and enable detection of a group of chemicals or provide an indication of a specific agent within a short time. Fast and robust point-of-need measurements would strongly contribute to the safety of inspectors, as well as locate chemical contamination.

Fieldable tests for assessing exposure to classical agents (biomedical samples)

Nerve agents

The most common method for rapid point-of-need diagnosis of exposure to nerve agents is based on nerve agent-induced changes on acetyl- or butyrylcholinesterase (AChE or BuChE) activity in blood.[53] However, large inter- and intra-individual variation of AChE activity in

[53] (a) "An Evaluation of Blood Cholinesterase Testing Methods for Military Health Surveillance". P. Knechtges, USACEHR Technical Report 0801, 2008;

blood remains a drawback to this approach. In order to draw firm conclusions about a possible exposure, the AChE inhibition level needs to be at least 40%.[54] In this regard, baseline values of individuals are of utmost importance. A selection of assays and devices based on AChE or BuChE inhibition are provided in Table 2. A simple lateral flow assay (LFA) or other immunochromatographic strip test would be ideal for rapid point-of-need diagnosis of nerve agent exposure. Unfortunately, specific antibodies against nerve agent-phosphylated cholinesterase are lacking due the phosphylated site in inhibited acetyl- or butyrylcholinesterase not being accessible for antibody recognition. A number of new technologies/approaches have been reported, which do not require the availability of specific antibodies (see Table 2).

Sulfur mustard

The majority of developments in the field of point-of-need diagnosis for chemical agents have focused on nerve agents. Nevertheless, point-of-need diagnostics for sulfur mustard exposure have been demonstrated which employ antibody-based detection of sulfur mustard adducts. Using this approach, field detection of skin exposure to sulfur mustard should be possible. Whether the same device that can detect skin exposure can also detect sulfur mustard adducts with blood constituents is not known. Example devices for detection of sulfur mustard exposure are provided in Table 2 (the list is not exhaustive and does not imply endorsement by the TWG or the SAB).

Table 2: Point-of-need technologies for assessment of exposure to nerve agents and sulfur mustard. This list provides a non-exhaustive overview, it does not represent recommendations of the TWG or the SAB.

Device	Manufacturer (Inventor)	Measurement Principle	Sensitivity	Matrices Tested	Commercially Available
Point-of-Need Diagnostic Devices for Nerve Agents					
Testmate[55]	EQM Research Inc.United States of America	AChE activity	> 20% inhibition	Blood	yes
ChECheck Mobile[56]	Securetec Detektions-Systeme AG, Germany	AChE or BuChE activity	> 20% inhibition	Blood	yes
Scentmate; lab on a chip[57]	DSO Laboratories, Singapore	AChE activity combined with fluoride reactivation	1 nM (in water)	Blood, water	no

https://pdfs.semanticscholar.org/4e1d/a9b503a57a85c2d7d38e827cb4f0c68dad51.pdf. (b) "A new and rapid colorimetric determination of acetylcholinesterase activity". G. L. Ellman, K. D. Courtney, V. Andres, Jr, R, M. Feather-Stone; Biochem. Pharmacol.; 1961, 7, 88-95. DOI: 10.1016/0006-2952(61)90145-9.

54 "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. Schilha, K. Neumaier, N. Aurbek, T. Wille, H. Thiermann, K. Kehe; *Toxicology Letters*; 2016, *249*, 22-28. DOI: 10.1016/j.toxlet.2016.03.007.

55 For further information, see: http://www.eqmresearch.com/.

56 For further information, see: https://www.securetec.net/en/rapid-test-determination-cholinesterase.

57 (a) "Lab-on-a-chip for rapid electrochemical detection of nerve agent sarin". H.-Y. Tan, W.-K. Loke, N.-T. Nguyen, S. Tan, Swee. N. B. Tay, W. Wang, S. H. Ng; *Biomedical microdevices*; 2013, *16*. DOI: 10.1007/s10544-013-9830-4. (b) "A lab-on-a-chip for detection of nerve agent sarin in blood". H.-Y. Tan, W.-K. Loke, Y. Tan, Yong, N.-T. Nguyen, Nam-Trung; *Lab on a chip*; 2008, *8*, 885-891. DOI: 10.1039/b800438b.

Device	Manufacturer (Inventor)	Measurement Principle	Sensitivity	Matrices Tested	Commercially Available
Immunosensor[58]	Pacific Northwest National Laboratory, United States of America	magnetic electrochemical immunoassay	8 pM	Water	yes
Lateral flow assay[59]	Central China Normal University	BuChE activity BuChE concentration	0.02 nM	Water	no
Disclosure test[60]	Institute for Pharmacology and Toxicology, Germany	AChE activity with Ellman-based read out	100 ng	Skin	no
Lateral flow assay	TNO, the Netherlands	Immunochemical determination of inhibited BuChE, after removal of native BuChE	5% inhibition in plasma Low µg on skin	Plasma and skin	no
Lateral flow assay[61]	Rapid Pathogen Screening, United States of America	Immunochemical detection of protein-nerve agent adduct	10 ng/mL	Blood	no
Enzyme ticket[62]	Neogen, United States of America	AChE activity	sub µg quantities	Skin	yes
Point-of-Need Diagnostic Devices for Sulfur Mustard					
Lateral flow assay[63]	Securetec Detektions-Systeme AG, Germany*	Immunochemical detection of sulfur mustard DNA adducts	2 µM	Skin	no
Immuno-chemical[64]	TNO, the Netherlands	Immunochemical detection of sulfur mustard keratin adducts	0.2 µM	Keratin and callus	no

58 "Carbon nanotube-based electrochemical sensor for assay of salivary cholinesterase enzyme activity: an exposure biomarker of organophosphate pesticides and nerve agents". J. Wang, C. Timchalk, Y. Lin; Environ. Sci. Technol. ; 2008, 42, 7, 2688-2693. DOI : 10.1021/es702335y.

59 "Integrated lateral flow test strip with electrochemical sensor for quantification of phosphorylated cholinesterase: biomarker of exposure to organophosphorus agents". D. Du, J. Wang, L. Wang, D. Lu, Y. Lin ; Anal. Chem.; 2012, 84(3), 1380-1385. DOI: 10.1021/ac202391w.

60 "Development of a sensitive, generic and easy to use organophosphate skin disclosure kit". F. Worek, A. Wosar, M. Baumann, H. Thiermann, T. Wille; *Toxicology Letters*; 2017, *280*, 190-194. DOI: 10.1016/j.toxlet.2017.08.021.

61 "A 10-minute point-of-care assay for detection of blood protein adducts resulting from low level exposure to organophosphate nerve agents". R. Vandine, U. Babu, P. Condon, A. Mendez, R. Sambursky; *Chemico-biological interactions* ; 2013, 203, 108-112. DOI : 10.1016/j.cbi.2012.11.011.

62 For further information, see: http://foodsafety.neogen.com/en/pesticides.

63 "Modified immunoslotblot assay to detect hemi and sulfur mustard DNA adducts". K. Kehe, V. Schrett, H. Thiermann, D. Steinritz; *Chem. Biol. Interact.*; 2013, *206(3)*, 23-28. DOI : 10.1016/j.cbi.2013.08.001.

64 (a) "Detection of Sulfur Mustard Adducts in Human Callus by Phage Antibodies ". F. Bikker, R. Mars-Groenendijk, D. Noort, A. Fidder, G. Schans; *Chemical biology & drug design.*; 2007, *69*, 314-20. DOI: 10.1111/j.1747-0285.2007.00504.x. (b) "Immunochemical detection of sulfur mustard adducts with keratins in the stratum corneum of human skin". G. P. van der Schans, D. Noort, R. H. Mars-Groenendijk, A. Fidder, L. F. Chau, L. P. A. de JongHendrik, P. Benschop ; *Chem. Res. Toxicol.*; 2002, *15*, 1, 21-25. DOI : 10.1021/tx0100136.

Device	Manufacturer (Inventor)	Measurement Principle	Sensitivity	Matrices Tested	Commercially Available
Immuno-chemical[65]	TNO, the Netherlands	Immunochemical detection of sulfur mustard adducts (DNA)	> 50 nM in blood > 1 s 830 mg/m^3 for skin	Blood and skin	no

*This product has been discontinued by this manufacturer.

Currently, the majority of the technologies described in Table 2, if in service, are being used in dedicated well-equipped laboratories. For this reason, it is important to further test the fieldability of the devices under real field/operational conditions. Point-of-need devices should be considered as indicative tests and verification of the results requires biomedical sample analysis performed using methods developed by the Designated Laboratories.[66]

Fieldable tests for assessing the presence of key toxins in environmental samples

For fieldable toxin tests, a number of point-of-need diagnostic devices for detecting the plant toxin ricin are available and summarized in Table 3. However, none of the devices listed in Table 3 (the list is not exhaustive and does not imply endorsement by the TWG or the SAB) are likely to differentiate between ricin and ricin agglutinin (RCA120),[67] a less toxic but highly homologous (90% identical) protein also found in castor beans. More sophisticated, laboratory-based methods, such as mass spectrometry, are required for differentiation and unambiguous identification. For reference, the sensitivity of commonly employed lab-based methods is listed below:

- ELISA kits have particularly high sensitivity: 0.002–0.5 ng/mL.[68]
- Surface Plasmon Resonance (SPR): 3 ng/mL, with differentiation between ricin and agglutinin possible.[69]
- Mass Spectrometry: 10-100 ng/mL, with differentiation between ricin and agglutinin possible.[70]

65 "Standard Operating Procedure for Immunuslotblot Assay for Analysis of DNA/Sulfur Mustard Adducts in Human Blood and Skin". G.P. van der Schans, R. Mars-Groenendijk, L.P.A. de Jong, H.P. Benschop, D. Noort; *J. Anal. Toxicology*; 2004, *28(5)*, 316–319. DOI: 10.1093/jat/28.5.316.

66 (a) See *Recommended operating procedures for analysis in the verification of chemical disarmament*. P. Vanninen (ed); University of Helsinki, Finland, 2017. For further information see: http://www.helsinki.fi/verifin/bluebook/. (b) For a list of Designated Laboratories the analysis of biomedical samples, see "Status of Designated Laboratories for the Analysis of Authentic Biomedical Samples" (S/1779/2019, dated 26 July 2019); www.opcw.org/sites/default/files/documents/2019/07/s-1779-2019%28e%29.pdf. (b) "Status of Laboratories Designated for the Analysis of Authentic Environmental Samples" (S/1775/2019, dated 23 July 2019): www.opcw.org/sites/default/files/documents/2019/07/s-1775-2019%28e%29.pdf.

67 S. Worbs, M. Skiba, M. Söderström, M.-L. Rapinoja, R. Zeleny, H. Russmann, H. Schimmel, P. "Characterization of ricin and r. communis agglutinin reference materials". Vanninen, S.-Å. Fredriksson, B. G. Dorner; *Toxins;* 2015, *7(12)*, 4906-4934. DOI: 10.3390/toxins7124856.

68 "Recommended immunological assays to screen for ricin-containing samples". S. Simon, S. Worbs, M.-A. Avondet, D, Tracz, J. Dano, L. Schmidt, H. Volland, B. Dorner, C. Corbett; Toxins; 2015, 7(12), 4967-4986. DOI: 10.3390/toxins7124858.

69 "Simultaneous differentiation and quantification of ricin and agglutinin by an antibody-sandwich surface plasmon resonance sensor". D. Stern, D. Pauly, M. Zydek, C. Müller, M.-A. Avondet, S. Worbs, F. Lisdat, M. B. Dorner, B. G. Dorner; *Biosens. Bioelectron.*; 2016, *78*, 111-7. DOI: 10.1016/j.bios.2015.11.020.

Point-of-need devices for detecting saxitoxin are also available. Representative examples are provided in Table 4 (the list is not exhaustive and does not imply endorsement by the TWG or the SAB).

On-site detection/identification of chemicals in the environment

Chemical warfare agents or other toxic substances used as chemical weapons may contaminate environments in a variety of ways. Corresponding to a wide range of possible scenarios, a variety of portable/hand-held detection devices are commercially available as chemical agent-specific and related chemical detectors. These devices are based on physical, chemical or enzymatic technologies and can detect either a group of chemicals or provide a concrete indication of a specific chemical within a short period of time. Table 5 summarises well-established technologies used in commercially available handheld systems[71] (the list is not exhaustive and does not imply endorsement by the TWG or the SAB). The "CBRNE Tech Index" database from MRI Global also contains a large list of CBRNE detection, collection, protection and analysis equipment.[72]

Table 3: Point-of-need devices/technologies for detection of ricin. This list provides a non-exhaustive overview and does not represent recommendations of the TWG or the SAB.
n.r. = not reported; n.d. = not detected with 20 ng/ml[74]

Device	Manufacturer (Inventor)	Measurement Principle	Sensitivity in Buffer	Matrices Tested	External Evaluation (proficiency test)
Lateral Flow Immunoassays (on-site detection, portable devices)					
BioThreat Alert Ricin	Tetracore United States of America	ELISA	*From manufacturer* 5 ng/mL *Other reported values* 6 ng/mL[73] 5 ng/mL[74] 3.6 ng/mL[75] 10 ng/mL[76]	Cosmetics[76] and various powders[73,75]	500 ng/mL[77]

70 “Analysis of ricin: analysis strategy”. M. Söderström, A. Bossée, B. G. Dorner, S. Worbs, L. Guo; Section 3, Part F in: P. Vanninen (ed). *Recommended operating procedures for analysis in the verification of chemical disarmament*, University of Helsinki, Finland, 2017, 547-579.

71 A 2015 review of hand-held chemical agent detectors may also be of interest. See: “Testing of hand-held detectors for chemical warfare agents”; A.-B. Gerber, *SPIEZ LABORATORY Annual Report 2015*, 38-39; https://www.labor-spiez.ch/pdf/en/dok/jab/88_003_e_laborspiez_jahresbericht_2015_web.pdf.

72 For further information, see: http://www.cbrnetechindex.com/.

73 “Evaluation of immunoassays and general biological indicator tests for field screening of Bacillus anthracis and ricin”. R. A. Bartholomew, R. M. Ozanich, J. S. Arce, H. E. Engelmann, A. Heredia-Langner, B. A. Hofstad, J. R. Hutchison, K. Jarman, A. M. Melville, K. D. Victry, C. J. Bruckner-Lea; *Health Secur.*; 2017, *15(1)*, 81-96. DOI: 10.1089/hs.2016.0044.

74 “Evaluating 6 ricin field detection assays”. H. C. Slotved, N. Sparding, J. T. Tanassi, N. R. Steenhard, N. H. Heegaard; *Biosecur Bioterror.*; 2014, *12(4)*, 186-189. DOI: 10.1089/bsp.2014.0015.

75 “Comprehensive laboratory evaluation of a highly specific lateral flow assay for the presumptive identification of ricin in suspicious white powders and environmental samples”. D. R. Hodge, K. W. Prentice, D. G. Ramage, S. Prezioso, C. Gauthier, T. Swanson, R. Hastings, U. Basavanna, S. Datta, S. K. Sharma, E. A. Garber, A. Staab, D. Pettit, R. Drumgoole, E. Swaney, P. L. Estacio, I. A. Elder, G. Kovacs, B. S. Morse, R. B. Kellogg, L. Stanker, S. A. Morse, S. P. Pillai; *Biosecur Bioterror.*; 2013, *11(4)*, 237-250. DOI: 10.1089/bsp.2013.0053.

76 “Rapid detection of ricin in cosmetics and elimination of artifacts associated with wheat lectin”. J. Dayan-Kenigsberg, A. Bertocchi, E. A. Garber; *J. Immunol. Methods*; 2008, *336(2)*, 251-254. DOI: 10.1016/j.jim.2008.05.007.

Device	Manufacturer (Inventor)	Measurement Principle	Sensitivity in Buffer	Matrices Tested	External Evaluation (proficiency test)
miPROTECT Ricin	Miprolab, Germany	ELISA	*From manufacturer* 5 ng/mL *Other reported values* 5 ng/mL[68] 20 ng/mL[78]	Milk,[78] meat extract,[78] beverages[68] cereals[68] and various powders[79]	500 ng/mL[77]
	CEA Saclay, France[80]	ELISA	*From manufacturer* 1 ng/mL *Other reported values* 1 ng/mL[78]	Milk and meat extract[78]	500 ng/mL[77]
BADD	AdVnt Biowarfare, United States of America	ELISA	*From manufacturer* 10 ng/mL *Other reported values* 400 ng/mL[73] n.d.[74]	Various powders[73]	
Pro Strips	AdVnt Biowarfare, United States of America	ELISA	*From manufacturer* 10 ng/mL *Other reported values* 100 ng/mL[73] n.d.[74]	Various powders[73]	
NIDS	ANP Technologies, United States of America	ELISA	*From manufacturer* n.r. *Other reported values* 25 ng/mL[73]	Various powders[73]	
BioDetect RAID 5	Alexeter Technologies, United States of America	ELISA	*From manufacturer* 6 ng/mL *Other reported values* 100 ng/mL[73]	Various powders[73]	
BioDetect RAID 8	Alexeter Technologies, United States of America	ELISA	*From manufacturer* 6 ng/mL *Other reported values* 1,600 ng/mL[73] n.d.[74]	Various powders[73]	
IMASS	BBI Detection, United Kingdom	ELISA	*From manufacturer* 1 ng/mL *Other reported values* 25 ng/mL[73] 10 ng/mL[74]	Various powders[73]	
ENVI	Environics Finland	ELISA	*From manufacturer* 5 ng/mL *Other reported values* 100 ng/mL[73]	Various powders[73]	
RAMP	Response Biomedical, Canada	ELISA	*From manufacturer* 100 ng/mL *Other reported values* 1,600 ng/mL[73] 14 ng/mL[81]	Various powders[73,81]	

77 "An international proficiency test to detect, identify and quantify ricin in complex matrices". S. Worbs, M. Skiba, J. Bender, R. Zeleny, H. Schimmel, W. Luginbühl, B. G. Dorner; *Toxins*; 2015; *7(12)*, 4987-5010. DOI: 10.3390/toxins7124859.

78 "Recommended immunological assays to screen for ricin-containing samples". S. Simon, S. Worbs, M.-A. Avondet, D. Tracz, J. Dano, L. Schmidt, V. Volland, B. Dorner, C. Corbett; *Toxins*; 2015, *7(12)*, 4967-4986. DOI: 10.3390/toxins7124858.

79 "On-site detection of bioterrorism-relevant agents: rapid detection methods for viruses, bacteria and toxins - capabilities and limitations". D. Stern, M. Richter, L. Schrick, P. Lasch, K. Keeren, A. Polleichtner, K. Lemmer, A. Nitsche, R. Grunow, C. Herzog, B. G. Dorner, L. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz*; 2016, *59(12)*, 1577-1586 (article in German).

80 Product is available through NBC-sys Saint Chamond, France.

Device	Manufacturer (Inventor)	Measurement Principle	Sensitivity in Buffer	Matrices Tested	External Evaluation (proficiency test)
Automated Immunoassays (on-site detection, portable devices)					
CANARY Zephyr	PathSensors, United States of America	IgG-B cells bioluminescence	*From manufacturer* 0.4 ng/mL *Other reported values* 3 ng/mL[73]	Various powders[73]	
pBDi (portable BioDetector)	Bruker Daltonics Jena, Germany	ELISA	0.5 ng/mL[82]	Beverages, food, powder matrices[82] milk, meat extract[77]	500 ng/mL[77]
BIOHAWK	Research International, Inc. United States of America	ELISA	*From manufacturer* 10 ng/mL		
RAPTOR	Research International Inc., United States of America	ELISA	*From manufacturer* 1 ng/mL		
Hand-Held Surface Plasmon Resonance (SPR) Device (on-site detection, portable devices)					
	not commercialised	Antibody binding, Surface Plasmon Resonance	200 ng/mL[83]		
PCR (on-site detection, portable device)					
RAZOR EX	BioFire Defense, United States of America	PCR	*From manufacturer* n.r.		
PCR (deployable laboratory device)					
FilmArray	BioFire Defense, United States of America	PCR	*From manufacturer* 1,000 ng/mL		

81 “Fluorogenic hand-held immunoassay for the identification of ricin: rapid analyte measurement platform”; R. E. Fulton, H. G. Thompson; *J. Immunoassay Immunochem.*; 2007, *28(3)*, 227-241. DOI: 10.1080/15321810701454730.

82 Robert Koch Institute, Berlin, Germany; unpublished results.

83 “A hand-held surface plasmon resonance biosensor for the detection of ricin and other biological agents”. B. N. Feltis, B. A. Sexton, F. L. Glenn, M. U. Best, M. Wilkins, T. J. Davis; *Biosens. Bioelectron.*; 2008, *23(7)*, 1131-1136. DOI: 10.1016/j.bios.2007.11.005.

Table 4: Point-of-need devices/technologies for detection of saxitoxin. This list provides a non-exhaustive overview, it does not represent recommendations of the TWG or the SAB.

Manufacturer (Inventor)	Sensitivity	Matrices Tested	External Evaluation (proficiency test)
ELISA Kits			
Abraxis, USA[84]	30 ppb 0,019 ng/ml in blood	Freshwater, shellfish, blood, artificial blood, dried blood	Yes[85]
Beacon, USA[86]	50 ppb 0,02 ng/ml in urine 0,02 ng/ml in plasma	Shellfish, urine, plasma	Yes[85]
Bioo Scientific[87]	3 ppb	Mussel, water	Yes[85]
R-biopharm, Germany[88]	50 ppb	Shellfish	Yes[85]
Europroxima, Netherlands[89]	10 ppb mussel; 5 ppb oyster	Scallop, mussel, oyster, Cockle, artificial urine	Yes[85] Was also included in a EuroBioTox[90] saxitoxin proficiency test
Creative Diagnostics, USA[91]	10-13 ppb	Freshwater, shellfish	
SeaTox Research, USA[92]	0,03 ppb	Shellfish	
Lateral Flow Assays			
Neogen, Scotland Neogen, USA[93]	0,03 ppb	Shellfish	
Neogen, Scotland[69]	680 ppb	Shellfish	Yes,[85] Inter-laboratory study[94]

84 For further information see: www.abraxiskits.com. See also "Quantification of saxitoxin in human blood by ELISA". R E. Wharton, M. C. Feyereisen, A. L. Gonzalez, N. L. Abbott, E. I. Hamelin, R. C. Johnson; *Toxicon*, 2017, *133*, 110 -115. DOI: 10.1016/j.toxicon.2017.05.009.

85 (a) "Application of rapid test kits for the determination of paralytic shellfish poisoning (PSP) toxins in bivalve molluscs from Great Britain". K. Harrison, S. Johnson, A. D. Turner; *Toxicon*, 2016, *119*, 352-361. DOI: 10.1016/j.toxicon.2016.06.019. (b) "Review of the currently available field methods for detection of marine biotoxins in shellfish flesh". C. McLeod, S. Burrell, P. Holland; 2015, FS102086 (This report has been produced by Seafood Safety Assessment Ltd. under a contract placed by the Food Standards Agency Scotland); https://www.food.gov.uk/research/marine-microbiology-and-biotoxins/review-of-the-currently-available-field-methods-for-detection-of-marine-biotoxins-in-shellfish-flesh.

86 For further information see: www.beaconkits.com. See also: (a) "Multiplexed ELISA screening assay for nine paralytic shellfish toxins in human plasma". P. Eangoor, A. Sanjay Indapurkar, M. D. Vakkalanka, J. S. Knaacka; *Analyst*, 2019, *144*, 4702-4707. DOI: 10.1039/C9AN00494G. (b) "Rapid and Sensitive ELISA Screening Assay for Several Paralytic Shellfish Toxins in Human Urine". P Eangoor, A. S. Indapurkar, M. Vakkalanka, J. S. Yeh, J. S. Knaack; *J. Anal. Toxicology*; 2017, *41(9)*, 755–759. DOI: 10.1093/jat/bkx072.

87 For further information see: www.biooscientific.com.

88 The product is no longer available.

89 For further information, see: http://europroxima.com/.

90 EuroBioTox: European programme for the establishment of validated procedures for the detection and identification of biological toxins; https://www.eurobiotox.eu//. See also, periodic reporting for EuroBioTox period 1: https://cordis.europa.eu/project/rcn/209945/reporting/de.

91 For further information, see: www.creative-diagnostics.com.

92 For further information see : www.seatoxresearch.com. See also: "Improved accuracy of saxitoxin measurement using an optimized enzyme-linked immunosorbent assay". J. R. McCall, W. C. Holland, D. M. Keeler, D. R. Hardison, R. W. Litaker; *Toxins*; 2019, *11(11)*, 632-643. DOI: 10.3390/toxins11110632.

93 For further information, see : www.neogeneurope.com and www.neogen.com.

94 "Detection of paralytic shellfish toxins in mussels and oysters using the qualitative neogen lateral-flow immunoassay: an interlaboratory study". J. J. Dorantes-Aranda, J. Y. C. Tan, Jessica, G. M. Hallegraeff, K. Campbell, S. C. Ugalde, D. T. Harwood, J. K. Bartlett, M. Campàs, S. Crooks, A. Gerssen, K. Harrison, A.-C. Huet, T. B. Jordan, M. Koeberl, T. Monaghan, S. Murray, R. Nimmagadda, C. Ooms, R. K. Quinlan, F. Shi, A. D. Turner, B. J. Yakes, A. R. Turnbull; *J. AOAC Intern.*; 2018, *101(2)*, 468-479. DOI: 10.5740/jaoacint.17-0221.

Manufacturer (Inventor)	Sensitivity	Matrices Tested	External Evaluation (proficiency test)
Scotia, Canada[95]	316 ppb mussel 710 ppb oyster	Shellfish	

Table 5: Well established technologies for commercially available portable/hand-held chemical detectors. This list provides a non-exhaustive overview, it does not represent recommendations of the TWG or the SAB.

Sample Types	Measurement Technology	Types of Chemicals Detected	Advantages and Disadvantages
Gaseous	Ion mobility spectrometry (IMS)	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high sensitivity + fast - poor selectivity - chemical specific device - false positives
Gaseous	Flame photometry (FPD)	Chemical warfare agents	+ high sensitivity + fast - non-agent specific
Gaseous	Surface acoustic wave (SAW)	Chemical warfare agents, drugs, explosives	+ database - sensitive to humidity/heat - poor selectivity
Gaseous	Fourier transformation infra-red (FTIR)	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high selectivity + database - low sensitivity
Gaseous	Photoionisation (PID)	Toxic industrial chemicals	- only for toxic industrial chemicals - chemical specific sensor
Gaseous	Colorimetry	Chemical warfare agents, toxic industrial chemicals	+ simple + low cost + disposable - slow - low sensitivity (except for nerve agents) - poor selectivity - chemical or chemical family specific test
Gaseous	Mass spectrometry (MS)	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high selectivity + high sensitivity + database - portability - more complex use - field use - chemical specific device
Liquids	Raman	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high selectivity + high sensitivity + database + fast + no direct contact with the samples - laser energy/explosion danger - difficulties with dark-colored samples - fluorescence - does not work with thick, non-transparent containers - not suitable for analysis of mixtures
Liquids	Fourier transformation infra-red (FTIR)	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high selectivity + high sensitivity + database + fast - direct contact with the samples - aqueous samples - mixtures

[95] For further information, see: www.jellett.ca.

Sample Types	Measurement Technology	Types of Chemicals Detected	Advantages and Disadvantages
Liquids	Colorimetry	Chemical warfare agents, toxic industrial chemicals	+ simple + low cost + disposable - slow - low sensitivity (except for nerve agents) - poor selectivity - chemical or chemical family specific test
Liquids	IMS or FPD with liquid detection sets	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high sensitivity + fast - poor selectivity - chemical specific device - false positives
Liquids	Mass spectrometry (MS)	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high selectivity + high sensitivity + database - portability - more complex use - field use - chemical specific device
Solids	Raman	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high selectivity + high sensitivity + database + fast + no direct contact with the samples - laser energy/explosion danger - difficulties with dark-colored samples - fluorescence - does not work with thick, non-transparent containers - not suitable for analysis of mixtures
Solids	Fourier transformation infrared (FTIR)	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high selectivity + high sensitivity + database + fast - direct contact with the samples - aqueous samples - mixtures
Solids	Mass spectrometry (MS)	Chemical warfare agents, drugs, explosive, toxic industrial chemicals	+ high selectivity + high sensitivity + database - portability - more complex use - field use - chemical specific device

In case of an event, it is important that on-site detection capabilities are quickly deployed. While large laboratory instruments offer a higher degree of sensitivity and measurement accuracy, they are unsuitable for on-site use. Portable/hand-held detection devices, such as those based on the technologies summarised in Table 5, are well suited for on-site analysis, however these require that a sample be taken off-site for confirmatory analysis.

Important considerations when choosing a detector are sensitivity and selectivity. The sensitivity refers to the detection limit of the device, while selectivity ensures that the device will correctly detect a particular agent in the presence of other chemicals that might interfere with the measurement. Detectors that fail to display an alarm despite the presence of a toxic chemical (e.g. false negative reading) can endanger personnel.

Other factors that should be considered include the fieldability of the detector, usability while wearing personal protective equipment, ease of use while working under intense time pressure, the scope and quality of the device integrated databases (and if the device has such a feature), as well as procurement and ownership costs.

Portable/hand-held detectors currently do not provide an unambiguous identification of a chemical. For this reason, orthogonal measurement methods involving the use of different systems with different detection techniques are routinely employed. The correct interpretation of the results requires a strong background and knowledge in the detection technique. Unambiguous identification of the chemicals should rely on further off-site analysis.

Recent developments with relevance to detection include a variety of colorimetric-based sensors,[96] biosensors,[97] miniaturization and portability of mass spectrometers,[98] specificity improvements of IMS methods,[99] wearable sensor technologies[100] and integration of on-site sensing systems onto unmanned aerial and ground platforms (e.g. UAVs and UGVs).[101] Information processing and data analytics also provide opportunities to integrate data collected on-site with remote monitoring equipment,[102] data collected with unmanned

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96 (a) "Colorimetric sensors for rapid detection of various analytes" A. Piriya V.S, P. Joseph, K. Daniel S.C.G., S. Lakshmanan, T. Kinoshita, S. Muthusamy; *Materials Science and Engineering*: *C*; 2017, *78*, 1231-1245. DOI 10.1016/j.msec.2017.05.018. (b) "Colorimetric Sensor Arrays for the Detection and identification of chemical weapons and explosives". M. J. Kangas, R. M. Burks, J. Atwater, R. M. Lukowicz, P. Williams, A. E. Holmes; *Crit. Rev. Anal. Chem.*; 2017, *47(2)*, 138-153, DOI: 10.1080/10408347.2016.1233805.

97 (a) "A review of current advances in the detection of organophosphorus chemical warfare agents based biosensor approaches". F. N. Diauudin, J. I. A. Rashid, V. F. Knight, W. M. Z. W. Yunus, K. K. Ong, N. A. M. Kasim, N. A. Halim, S. A. M. Noor; *Sensing and Bio-Sensing Research*; 2019, *26*, 100305. DOI: 10.1016/j.sbsr.2019.100305. (b) "Detection methodologies for pathogen and toxins: a review"; M. D. Eshrat, E. Alahi, S. C. Mukhopadhyay; *Sensors*; 2017, *17(8)*, 1885; DOI: 10.3390/s17081885. (c) "Advances in biosensor technology for potential applications – an overview". S. Vigneshvar, C. C. Sudhakumari, B. Senthilkumaran, H. Prakash Hridayesh; *Frontiers Bioeng. Biotech.*; 2016, *4*. DOI: 0.3389/fbioe.2016.00011.

98 (a) "Deploying portable gas chromatography–mass spectrometry (GC-MS) to military users for the identification of toxic chemical agents in theatre". P. E. Leary, B. W. Kammrath, K. J. Lattman, G. L. Beals; *Applied Spectroscopy*; 2019, *73(8)*, 841–858. DOI: 10.1177/0003702819849499. (b) "The emergence of low-cost compact mass spectrometry detectors for chromatographic analysis". X. Bu, E. L. Regalado, S. E. Hamilton, C. J. Welch; *Trends in Anal. Chem.*; 2016, *82*, 22-34. DOI: 10.1016/j.trac.2016.04.025. (c) "Ambient ionization mass spectrometry for point-of-care diagnostics and other clinical measurements". C. R. Ferreira, K. E. Yannell, A. K. Jarmusch, V. Pirro, Z. Ouyang, R. G. Cooks; *Clinical Chem.*; 2016, *62(1)*, 99–110. DOI: 10.1373/clinchem.2014.237164.

99 (a) "Ion Mobility Spectrometry: Fundamental Concepts, Instrumentation, Applications, and the Road Ahead". J. N. Dodds, E. S. Baker; *J. Am. Soc. Mass Spectrom.*; 2019, *30*, 2185–2195 DOI: 10.1007/s13361-019-02288-2. (b) "Ultra-high-resolution ion mobility spectrometry—current instrumentation, limitations, and future developments". A. T. Kirk, A. Bohnhorst, C. R. Raddatz, M. Allers, S. Zimmermann; Anal. Bioanal. Chem.; 2019, 411, 6229-6246. DOI: 10.1007/s00216-019-01807-0 (c) "Ion mobility spectrometry: current status and application for chemical warfare agents detection". J. Puton, J. Namieśnik; *Trends Anal. Chem.*; 2016, *85*, 10-20. DOI: 10.1016/j.trac.2016.06.002.

100 (a) "Wearable chemical sensors: emerging systems for on-body analytical chemistry". J. R. Sempionatto, I. Jeerapan, S. Krishnan, J. Wang; *Anal. Chem.*; 2019. DOI: 10.1021/acs.analchem.9b04668. (b) "Chem/bio wearable sensors: current and future direction". R. Ozani; *Pure Appl. Chem.*; 2018, *90(10)*, 1605-1613. DOI: 10.1515/pac-2018-0105.

101 (a) "Environmental applications of small unmanned aircraft systems in multi service tactics, techniques, and procedures for chemical, biological, radiological, and nuclear reconnaissance and surveillance". B. B. Barnes; *Technical Report, 01 Aug 2015, 23 Mar 2017*; Air Force Institute Of Technology Wright-Patterson AFB OH Wright-Patterson AFB United States, 2017; https://apps.dtic.mil/docs/citations/AD1055173. (b) "Drones swarm to science: flying robots are doing experiments too hazardous, too expensive, or simply impossible for humans". S. Everts, M. Davenport; *C&E News*; *94(9)*, 32-33 (and other articles linked from this introduction).

102 (a) "Remote chemical sensing: a review of techniques and recent developments". R. Bogue; *Sensor Review*; 2018, *38(4)*, 453-457. DOI: 10.1108/SR-12-2017-0267. (b) "Laser based standoff techniques:

systems and satellite imagery[103] in real-time. The SAB has reported new developments in detection technologies to the Fourth Review Conference.[42]

Limitations in available portable/hand-held detection systems include:

- Lack of universal detectors for the broad classes of chemical threat agents.

- On-site detection technologies are available for a variety of biological toxins. However, these often lack the necessary sensitivity and specificity to detect toxic doses from environmental or clinical samples and have not been validated comprehensively on the numerous known toxin variants. Sampling and analysis of biological toxins are further discussed in the sections of this report from Sub-group C that follow.

- Lack of robustness. High levels of vibration, as well as temperature, pressure and humidity variations, can affect the fieldability and suitability of the detector.

While discussion around Convention-relevant detection technologies have historically focused on chemical warfare agents, the changing threat environment necessitates that attention also be paid to detection technologies for TICs and other potential chemical threat agents. Relevant examples of TICs include chlorine, ammonia, phosgene and hydrogen cyanide. There are many available on-site detection systems for TICs in use at industrial sites and by emergency-responders; several examples including detection technologies suitable for the CNS-acting chemical fentanyl, are provided in Table 6.

Table 6: Examples of technologies for environmental detection of toxic industrial chemicals (TICs) and fentanyl. This list provides a non-exhaustive overview, it does not represent recommendations of the TWG or the SAB.

Device	Producer/ Inventor	Measuring Principle	Reported Sensitivity	Matrices Tested	Available
General List					
Autonomous Chemical Vapour Detection by Micro UAV[104]	DST Group. Australia	Optical colorimetric spectrometer,	1 – 10 ppm	Vapour cloud	

a review on old and new perspective for chemical detection and identification". P. Gaudio; in: M. Martellini A. Malizia (eds), *Cyber and Chemical, Biological, Radiological, Nuclear, Explosives Challenges. Terrorism, Security, and Computation*; Springer, Cham, 2017. DOI: 10.1007/978-3-319-62108-1_8. (c) "Review of explosive detection methodologies and the emergence of standoff deep UV resonance Raman". K. L. Gares, K. T. Hufziger, S. V. Bykov, S. A. Asher; *J. Raman Spec.*; 2016, *47(1)*, 124-141. DOI: 10.1002/jrs.4868. (d) "Explosive and chemical threat detection by surface-enhanced Raman scattering: a review"; *Anal. Chim. Acta*; 2015, *893*, 1-13. DOI: 10.1016/j.aca.2015.04.010.

103 See for example: (a) "Reconstructing chemical plumes from stand-off detection data of airborne chemicals using atmospheric dispersion models and data fusion". O. Björnham, H. Grahn, N. Brännström, 2018, *Pure Appl. Chem.*; *90(10)*, 1577–1592, DOI: 10.1515/pac-2018-0101. (b) "The 2016 Al-Mishraq sulphur plant fire: source and health risk area". O. Björnham, H. Grahn, P. von Schoenberg, B. Liljedahl, A. Waleij, N. Brännström; *Atmospheric Env.*; 2017, *169*, 287-296. DOI: 10.1016/j.atmosenv.2017.09.025.

104 "Autonomous chemical vapour detection by micro UAV". K. Rosser, K. Pavey, N. FitzGerald, A. Fatiaki, D. Neumann, D. Carr, B. Hanlon, J. Chahl ; *Remote Sens.*, 2015, *7*, 16865-16882. DOI : 10.3390/rs71215858.

Device	Producer/ Inventor	Measuring Principle	Reported Sensitivity	Matrices Tested	Available
EIC SERSanalyser [105]	EIC Laboratories Inc., United States of America	Surface-Enhanced Raman Spectroscopy, Raman Spectroscopy	ppb (50-100)	Vapours, Liquids	Reported
Portable ion trap MS Mini 10, and Mini S low weight 12 and 10 kg[106]	Aston Labs, Purdue University, United States of America	Mass spectrometry	ng level	Liquid, powder	Reported
Fieldable – Portable Guardio -7 GC/MS weight 13kg[106]	Torion Technologies (recently acquired by Perkin Elmer), United States of America	Ion trap mass analyzer	ppb level	Liquid	
Hand-held miniature mass spectrometer with novel inlets Weight < 8 kg[107]	1st Detect Corporation, United States of America	Cylindrical ion trap based mass spectrometer	< 1 ppb	Liquid	
Low cost colorimeter using graphene and carbon nanotubes combined with nanoparticles[108]	Orth Group. Federal University of Parana, Brazil	Catalytic degradation		Agricultural fields	Reported
Gas Analyzer GT5000 Terra[109]	Gasmet, Finland	FTIR	ppb level	Gaseous	Yes
Multi-Gas Monitor X-am[110]	Dräger	Catalytic, Electrochemical, Infrared	ppm level	Gaseous	Yes
Ammonia					
Ammonia analyzer[111]	PocketChem BA®, Japan	Colorimetric, reflectance spectroscopy, micro diffusion	7 and 286 µmol/l	Blood	Yes
Dräger-Tubes®[112]	Dräger, 7 Solutions, Gastec, Honeywell	Colorimetric tubes	0.25 – 600 ppm	Gaseous	Yes

105 For further information, see: www.eiclabs.com.

106 "Chemical sniffing instrumentation for security applications". S. Giannouko, B. Brkić, S. Taylor, A. Marshall, G. F. Verbeck; *Chem. Rev.*; 2016, *116*, 14, 8146-8172. DOI: 10.1021/acs.chemrev.6b00065.

107 For further information, see: https://www.1stdetect.com/.

108 "Targeted catalytic degradation of organophosphates: pursuing sensors". L. Hostert, B. Campos, J. E. S. Fonsaca, V. B. Silva, S. F. Blaskievicz, J. G. L. Ferreira, W. Takarada, N. Naidek, Y. H. Santos, L. L. Q. Nascimento, A. J. G. Zarbin, E. S. Orth; Pure Appl. Chem,; 2018, 90(10), 1593–1603. DOI: 10.1515/pac-2018-0104.

109 For further information, see: https://www.gasmet.com/products/category/portable-gas-analyzers/gt5000-terra/.

110 For further information, see: https://www.draeger.com/en-us_us/Applications/Productselector/Portable-Gas-Detection/Multi-Gas-Detectors.

111 "Accuracy of a point-of-care ammonia analyzer for screening of blood ammonia in pediatric patients with inborn error of metabolism". P. Tovichien, P. Luenee, P. Tientadakul, N. Vatanavicharn; *Southeast Asian J. Trop. Med. Public Health*, 2017, *48 (Supplement 2)*, 133-140; https://www.tm.mahidol.ac.th/seameo/2017-48-suppl-2/2017-48-supp2-133.pdf.

112 For further information, see: https://www.draeger.com/en_uk/Products/Sampling-Tubes-and-Systems.

Device	Producer/ Inventor	Measuring Principle	Reported Sensitivity	Matrices Tested	Available
X-am XXS NH_3[110]	Dräger	Electrochemical	0 – 300 ppm	Gaseous	Yes
Chlorine					
Mobile platform for chlorine monitoring[113]	National Science and Technology Development Agency, Thailand	Colorimetry	0.06–2.0 ppm	Chlorine, water	
Dräger-Tubes®[112]	Dräger	Colorimetric tubes	0.2 – 500 ppm	gaseous	Yes
X-am XXS Cl_2[110]	Dräger	Electrochemical	0 – 20 ppm	gaseous	Yes
Hydrogen Cyanide					
Dräger-Tubes®[112]	Dräger	Colorimetric tubes	0.5 – 10 mg/L 0.5 -50 ppm	Liquid gaseous	Yes
X-am XXS HCN[110]	Dräger	Electrochemical	0 – 50 ppm	gaseous	Yes
Phosgene					
Test Strip (OPD-TPE-Py-2CN)[114]	State Key Laboratory of Luminescent Materials and Devices, College of Materials Science and Engineering, South China University of Technology, Guangzhou	AIE-based fluorophores.	1.87 ppm	Gaseous phosgene	Yes
Phosgene second-generation chemosensor[115]	Department of Chemistry and Nano Science, Ewha Womans University, Seoul, Republic of Korea	Fluorescent and colorimetric	3.2 ppb.	Gaseous phosgene	Reported
Dräger-Tubes®[112]	Dräger	Colorimetric tubes	0.02 – 5 ppm	gaseous	Yes
X-am XXS $COCl_2$[110]	Dräger	electrochemical	0 – 10 ppm	gaseous	Yes
Fentanyl					
TC-DART-MS and IMS[116]	IonSense, United States of America IMS: Nomex®, Smiths Detection, United Kingdom	Thermal desorption direct analysis in real time mass spectrometry, and ion mobility spectrometry	ng level	Wipe	Yes
The Rapid Response™ Fentanyl (FYL) Forensic Test Kit[117]	BTNX Inc., United States of America www.btnx.com	Lateral flow immunoassay	200 ng/mL	Liquid, powder	Yes

113 “Mobile-platform based colorimeter for monitoring chlorine concentration in water”. S. Sumriddetchkajorn, K. Chaitavon, Y. Intaravanne, *Sens. Act. B: C.*; 2014, *191*, 561-566. DOI : 0.1016/j.snb.2013.10.024.

114 “An AIE-based fluorescent test strip for the portable detection of gaseous phosgene”. H. Xie, Y. Wu, F. Zeng, J. Chena, S. Wu; *Chem. Commun.*; 2017, *53*, 9813-9816. DOI: 10.1039/C7CC05313D.

115 “Colorimetric and fluorescent detecting phosgene by a second-generation chemosensor”. Y Hu, X. Zhou, H. Jung, S.-J. Nam, M. H. Kim, J. Yoon; *Anal. Chem.*; 2018, *90(5)*, 3382-3386. DOI: 10.1021/acs.analchem.7b05011.

116 “Rapid detection of fentanyl, fentanyl analogues, and opioids for on-site or laboratory based drug seizure screening using thermal desorption DART-MS and ion mobility spectrometry”. E. Sisco, J. Verkouteren, J. Staymates, J. Lawrence; *Forensic Chemistry*; 2017, *4*, 108-115. DOI: 10.1016/j.forc.2017.04.001.

Device	Producer/ Inventor	Measuring Principle	Reported Sensitivity	Matrices Tested	Available
Gemini[118]	ThermoFisher Scientific	FTIR, Raman		Powder, wipe	Yes
Mira DS[119]	Metrohm	Raman		Powder, wipe	Yes
Resolve[120]	Agilent	Raman		Powder, wipe	Yes
Progeny ResQ FLX[121]	Rigaku	Raman		Powder, wipe	Yes
Guardion[122]	Smiths Detection	Gas chromatography mass spectrometer	ppb	Liquid	Yes
Griffin G510[123]	FLIR Systems, Inc.	Gas chromatography mass spectrometer	ppb	Liquid	Yes

Laboratory analysis for exposure to chemical weapons, including toxins and toxic industrial chemicals (TICs) used as weapons

After the deliberate release of a chemical warfare agent, it may be difficult to find traces of the chemical that was used. Some agents evaporate or degrade very rapidly, and especially when the scene of the incident is decontaminated, the persistency of chemical agents would be further compromised. However, when humans are exposed to a chemical warfare agent, traces may be found in tissue samples for longer periods of time. Sarin attacks in the Syrian Arab Republic and the subsequent United Nations-led investigations revealed that in addition to environmental samples, biomedical samples such as blood and urine were crucial for unequivocal assessment of the use of chemical weapons.[27(a)] For instance, the presence of sarin-related fingerprints in human tissue of a deceased victim has been well documented.[48(a)] The OPCW has maintained a network of designated laboratories for biomedical sample verification since 2016.[66(b)]

Biomedical sample analysis of chemical warfare agent exposure using dried bloods has been recently demonstrated.[124] This enables easier transport of blood samples, while still maintaining the integrity of the sample.

The capabilities of expert laboratories to verify the presence of biological toxins is being addressed by the European programme for the establishment of validated procedures for the

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117 "Evaluation of a fentanyl drug checking service for clients of a supervised injection facility, Vancouver, Canada". M. Karamouzian, C. Dohoo, S. Forsting, R. McNeil, T. Kerr, M. Lysyshyn; *Harm Reduct. J.*; 2018, *15*, 46. DOI: 10.1186/s12954-018-0252-8

118 For further information, see: https://www.thermofisher.com/nl/en/home/industrial/spectroscopy-elemental-isotope-analysis/portable-analysis-material-id/chemical-explosives-narcotics-identification/gemini-ftir-ftir-raman-handheld-analyzer.html.

119 For further information see: https://www.metrohm.com/en/products/spectroscopy/mira-handheld-raman-spectrometers/mira-ds-landing-page/.

120 For further information, see: https://www.agilent.com/en/promotions/resolve.

121 For further information, see: https://www.rigaku.com/products/raman/flx.

122 For further information, see: https://www.cbrnetechindex.com/p/3508/Smiths-Detection-Inc/contact.

123 For further information, see: https://www.flir.com/products/griffin-g510/.

124 (a) "Instantaneous monitoring of free sarin in whole blood by dry blood spot–thermal desorption–GC–FPD/MS analysis"; D. Marder, S. Dagan, L. Yishai-Aviram, D. Loewenthal, S. Chapman, R. Adani, S. Lazar, A. Weissberg, S. Gura; *J. Chromatography B*; 2020, *1136*, 121911. DOI: 10.1016/j.jchromb.2019.121911. (b) Shaner et al., 2018; Hamelin et al, 2016; Perez et al, 2015, all from the CDC laboratory

detection and identification of biological toxins (EuroBioTox).[125] The OPCW has also initiated biotoxin analysis exercises to improve capabilities.[126] The eventual verification of toxins will rely on an off-site network of laboratories.

Detection of HMW protein-based toxins requires very different technologies, tools, instrumentation and expertise compared to that of LMW toxins, such as saxitoxin.[127] The LMW toxins are amenable to classic chemical analytical methods, while analysis of ricin and other HMW toxins involve methods more characteristic of laboratories that carry out biological analyses. For forensic purposes, analysis of ricin must demonstrate chemical composition, structure and biological activity.

Few laboratories are skilled in both HMW and LMW toxin analysis and given the diversity of molecules within both classes, specialisation on specific groups of toxins would further separate laboratory capability. In particular, laboratories that analyse chemical warfare agents may not be equipped for the analysis of the broad variety of HMW toxins. Also, laboratories that are skilled in analysis of HMW toxins may not have expertise in analysis of LMW toxins. A consequence of this is that the groups of laboratories which contribute to RefBio (Germany's Contribution to Strengthen the Reference Laboratories Bio in the UNSGM),[128] EuroBioTox or serve as Designated Laboratories have little overlap. This makes it unlikely that a single network of laboratories could be designated for detection of both LMW and HMW toxins.

Many methods and techniques for assessment of TICs in environmental samples have been reported within the framework of environmental monitoring studies, these include evaluations of commercially available screening technologies,[129] wipe sampling methods applicable to both chemical warfare agents and TICs,[130] and sample preparation techniques.[131] For methods for exposure assessment (including biomonitoring techniques and biomedical sample analysis) of TICs have also been developed within the framework of

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125 EuroBioTox: European programme for the establishment of validated procedures for the detection and identification of biological toxins; https://www.eurobiotox.eu//. See also, periodic reporting for EuroBioTox period 1: https://cordis.europa.eu/project/rcn/209945/reporting/de.

126 See paragraphs 9.9 to 9.10 of "Report of the Scientific Advisory Board at its Twenty-Seventh Session" (SAB-27/1, dated 23 March 2018); www.opcw.org/sites/default/files/documents/SAB/en/sab-27-01_e_.pdf. (b) See paragraph 9.6 of "Report of the Scientific Advisory Board at its Twenty-Sixth Session" (SAB-26/1, dated 20 October 2017); www.opcw.org/sites/default/files/documents/SAB/en/sab-26-01_e_.pdf (c) See also: "Call for Nominations for the Fourth Exercise on the Analysis of Biotoxins" (S/1780/2019, dated 29 July 2019); www.opcw.org/sites/default/files/documents/2019/07/s-1780-2019%28e%29.pdf.

127 See paragraphs 10.15 to 10.19 of SAB-29/WP.1 (referenced in footnote 13(d))

128 RefBio: German Contribution to Strengthen the Reference Laboratories Bio in the UNSGM; https://www.rki.de/EN/Content/Institute/International/Biological_Security/RefBio.html.

129 *Technology Evaluation Report Testing of Screening Technologies for Detection of Toxic Industrial Chemicals in All Hazards Receipt Facilities*. T. W. Kelly, M. M. Baxter, E. N. Koglin; U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/034, 2008; https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHSRC&subject=Homeland%20Security%20Research&dirEntryId=189630.

130 *A Literature Review of Wipe Sampling Methods for Chemical Warfare Agents and Toxic Industrial Chemicals*. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-11/079, 2007; https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHSRC&subject=Homeland%20Security%20Research&dirEntryId=238670.

131 "New trends in sample preparation techniques for environmental analysis, critical reviews in analytical chemistry". C. Ribeiro, A. R. Ribeiro, A. S. Maia, V. M. F. Gonçalves. M. E. Tiritan; *Crit. Rev. Anal Chem.*; 2014, *44(2)*, 142-185. DOI: 10.1080/10408347.2013.833850.

occupational hygiene and environmental health.[132] With the development of more sensitive mass spectrometers, many methods have been developed for individual chemicals (or their reactive metabolites) based on the sensitive analysis of covalent adducts to proteins and/or DNA, and/or on the analysis of urinary metabolites (in case of less reactive chemicals).[133]

A recurring problem is identifying the presence of increased levels of certain chemicals (especially those that are volatile and non-persistent), for which normal background levels exist in the environment and/or within a biological system (e.g. in animals and microorganisms), in this context chlorine is a relevant example.

Chlorine is a potent oxidising agent and the oxidative damage of lung tissues is the most serious injury of exposed victims.[134] Chlorine also modifies unsaturated (i.e. containing double carbon bonds) biomolecules through an electrophilic addition reaction. In contrast to the oxidative pathway, the chlorination pathway has the potential to produce ambiguous markers for chlorine use and exposure. Chlorinated tyrosines present in respiratory tract proteins were the first biomarkers suggested for verification of chlorine exposure,[135] and detection of the markers in blood, serum and plasma samples has recently been presented as a potential method with high sensitivity[136]. Chlorotyrosines, however, are also well-documented markers of oxidative stress, which are important to monitor in patients suffering from oxidative diseases to support their use for unambiguous verification. Chlorinated phospholipids present in the lung fluid of chlorine-exposed mice have been identified as alternative biomarkers.[137] Their formation in the lung surfactant has the potential to produce markers selective for chlorine; however, the sample collection requires advanced equipment. Both methods require further development to assess their value as tools for verification of chlorine exposure.

The verification of alleged use of chlorine by chemical analysis of environmental samples such as soil is difficult due to the formation of only non-specific and naturally occurring products by chlorine degradation (e.g. inorganic chloride). However, the electrophilic addition of chlorine to unsaturated compounds, already described, will also take place in vegetation. Spiez Laboratory has identified specific chlorinated biomolecules in different vegetation samples (e.g. wood), which were in contact with chlorine gas or reactive chlorine-containing chemicals.[138] A benefit of the wood biomarkers is long persistence since wood is a dead tissue without any cellular metabolism.

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132 "Biomonitoring: measuring chemicals in people". D. Farquha; Nationjal Conference of State Legislatures, 2017; http://www.ncsl.org/research/environment-and-natural-resources/biomonitoring-measuring-chemicals-in-people636390779.aspx

133 "Human biomonitoring: State of the art". J. Angerer, U. Ewers, M. Wilhelm; *Int. J. Hygiene Env. Health*; 2007, *210(3-4)*, 201-228, DOI: 10.1016/j.ijheh.2007.01.024.

134 "Toxic effects of chlorine gas and potential treatments: a literature review". A. Satyanarayana, S.-E. Jordt; *Toxicol. Mech. Methods*; 2019, *1*, 1-13 DOI:10.1080/15376516.2019.1669244

135 "Chlorotyrosine and 3,5-dichlorotyrosine as biomarkers of respiratory tract exposure to chlorine gas". M. A. Sochaski, A. M. Jarabek, J. Murphy, M. E. Andersen; *J. Anal. Tox.*; 2008, *32(1)*, 99–105, DOI: 10.1093/jat/32.1.99.

136 Simultaneous measurement of 3-chlorotyrosine and 3,5-dichlorotyrosine in whole blood, serum, and plasma by isotope dilution HPLC-MS/MS". B. S. Crow, J. Quiñones-González, B. G. Pantazides, J. W. Perez, W. Rucks Winkeljohn, J. W. Garton, J. D. Thomas, T. A. Blake, R. C. Johnson; *J. Anal. Tox.*; 2016, *40(4)*, 264–271. DOI: 10.1093/jat/bkw011.

137 *l*-α-Phosphatidylglycerol chlorohydrins as potential biomarkers for chlorine gas exposure". P. Hemström, A. Larsson, L. Elfsmark, C. Åstot; *Anal. Chem.*; 2016, *88(20)*, 9972-9979. DOI: 10.1021/acs.analchem.6b01896.

138 See paragraphs 8.7 to 8.9 of "Report of the Scientific Advisory Board at its Twenty-Third Session, 18 – 22 April 2016" (SAB-23/1, dated 22 April 2016); www.opcw.org/sites/default/files/documents/SAB/en/sab-23-01_e_.pdf.

Recommendations of Sub-group C

Recommendation: *Enhance capabilities for the on-site detection of chemical warfare agents and related compounds, including newly scheduled agents,[16] TICs, CNS-acting chemicals, and biological toxins, from a variety of environmental matrices, including gaseous, liquid and solid forms, to offer a broad coverage of possible scenarios*.

Fast and robust detection tools that can provide information at the point of measurement or the point-of-need (e.g., analogous to a point-of-care use in a clinical setting) are needed for a broader range of scenarios. These would support an inspection team in collecting samples on-site, as well as enhancing its safety. The selection of detection equipment used for a mission should be based on available information and risk assessment in advance of deployment.

Recommendation: *Continuously monitor and identify gaps in sampling and analysis capabilities for chemical threat agents, to enable the Secretariat to mitigate the consequences of those gaps.*

The Secretariat should draw upon established sources, expert communities, chemical industry and manufacturers of equipment to efficiently gain access to knowledge and capabilities. Areas of relevance include technologies for sampling, detection, and analysis; automated and robotic systems; and for the analysis of inorganic compounds, TICs and CNS-acting chemicals.

Recommendation: *Scenarios developed for mission planning and training should be adapted for the purpose of evaluating sampling and detection systems to meet mission conditions.[20]*

Where possible the Secretariat should seize opportunities to use scenario-based field exercises to evaluate available equipment to determine its fieldability to meet operational requirements. Evaluation of equipment could be an activity at OPCW's future Centre for Chemistry and Technology.[21] The Secretariat could also draw upon equipment evaluations available from Member States.

Recommendation: *Work towards a greater degree of agility and flexibility regarding procurement of equipment by the Secretariat.*

A market watch function within the Secretariat to closely follow developments in relation to the operational needs would help to facilitate more efficient evaluation and procurement processes. For non-routine missions, this would allow the Secretariat to more rapidly adopt new technologies, which are especially important when considering the changing nature of threats and operational scenarios.

Recommendation: *Ensure the Secretariat's analytical chemists and Designated Laboratories have access to procedures and analytical data needed for detection and identification of emerging chemical threat agents.*

In addition to those of scheduled chemicals, add spectra, where available, of relevant unscheduled and newly scheduled chemicals to the OCAD, for on-site and off-site identification purposes. Provide procedures for on-site analysis of newly scheduled agents, TICs, CNS-acting chemicals and biological toxins.

Recommendation: *Ensure that the Secretariat has access to capabilities for verification and response to threats from TICs.*

> This would include defining and maintaining a prioritized TIC-list that includes the most likely types of chemicals for which capabilities might be required. Engaging with experts in biomonitoring and biomedical analysis methods for TICs, and with those handing and monitoring TICs in chemical industry would also help to ensure that the Secretariat is fully aware of state-of-the-art methods for sampling and analysis of TICs.

Recommendation: *Consider establishing a new TWG on how to ensure that the Secretariat has access to required capabilities for the analysis of relevant biological toxins.*

> Discussions should bring together SAB members, representatives of Designated Laboratories, and other experts in biological toxin analysis. Given the broad diversity of techniques required for toxin analysis, understanding the capabilities of a wider group of laboratories that perform analyses of toxins, in particular, High Molecular Weight (HMW) toxins, would be critical should toxin analysis be required for an investigation. An approach to overcoming capability limitations could be to rely on outside proficiency testing exercises to identify those laboratories experienced in the analysis of HMW toxins specifically, highly toxic protein toxins. Laboratories supporting the United Nations Secretary-General's Mechanism (UNSGM)[25,26] have experience with analysis of HMW toxins, and could, likewise, potentially seek laboratory and other support from OPCW Designated Laboratories that are proficient in analysis of low molecular weight (LMW) toxins.

Recommendation: *Increase analytical capabilities for new chemical threat agents, in particular newly scheduled nerve agents.*[16]

> More specifically to: detect such chemicals in the field, both to protect inspectors and to allow them to carry out verification or assistance activities; and, to have reference standards and data for these chemicals, and their precursors and degradation products, in order to establish recommended analytical methods and to enable comparison of measurements and spectra. Related considerations are also discussed in the Sub-group F section.

Sub-group D: Integrity of the Scene and Evidence Collection

Sub-group D was tasked to address maintaining the integrity of an investigation site, and evidence collection, with focus on the questions from sub-paragraphs 4(d), 4(h) and 4(i) of the TWG's TOR, which are:

- What are the best practices for the collection, handling, curation and storage, and annotation of evidence?

- Which technologies and methodologies (whether established or new) can be used in ensuring chain of custody and verifying authenticity (especially in regard to digital images and video recordings)?

- Which technologies and methodologies (whether established or new) can be used to ensure the integrity of an investigation site?

The sub-group looked at four priority areas to address the assigned questions:

- Evaluate current procedures and compare to forensic best practices from collection through to archiving and curation. This could include tracking of associated metadata.

- The sub-group noted that sample transport should also be considered.

- Review best practices used in field investigations. Consider the best approach to the development of guidelines.

- Explore how others approach the reconstruction of past events and physical locations.

<u>Best practices for the collection, handling, curation and storage, and annotation of evidence</u>

Organisations conducting forensic investigations and/or examinations are normally required to have a best practice manual. If an organization has ISO accreditation,[139] there would be an expectation that it would also encompass forensic investigations. Currently there are no all-encompassing best practice manuals. The actual "best practices" depend on the type of crime scene and the evidence that should be recovered (for example, whether it is a sample, or there is need to recover an item in its totality). In defining best practices, much can be learned from other organisations in regard to forensics and investigative work.

The European Union (EU)

The European Union (EU) considers forensic investigation to be a key component in the fight against CBRN related criminal activity which has been hampered by a lack of protocols and training in carrying out forensic analysis on CBRN-contaminated materials.[140] To address this gap, a "Generic Integrated Forensic Toolbox for CBRN incidents", the (GIFT CBRN) project was initiated under the EU's Seventh Framework Programme (FP7).

The GIFT project defines CBRN forensics as:

- The collection of CBRN materials at an incident scene and its laboratory investigation to determine the origin of the material and attribute it to a certain event.

- The collection of regular forensic evidence in an environment that is (potentially) contaminated with CBRN materials, requiring specialized procedures, equipment and training to safely collect this type of evidence.

- A combination of the above, where both CBRN evidence as well as regular forensic

139 ISO: Organization for Standardization. For further information see https://www.iso.org/home.html.

140 For further information, see: https://cordis.europa.eu/project/id/608100. See also: Final Report Summary - GIFT CBRN (Generic Integrated Forensic Toolbox for CBRN incidents), European Commission, 2018; https://cordis.europa.eu/project/id/608100/reporting. For previous discussions within the TWG on GIFT Forensics, see: paragraphs 8.16 to 8.18 SAB-28/WP.3 (referenced in footnote 13(c)) and paragraphs 6.8 to 6.9 of SAB-29/WP.1 (referenced in footnote 13(d)).

evidence needs to be collected at an incident scene contaminated with CBRN materials.

The overarching aim of GIFT CBRN was to develop a forensic toolbox for investigating CBRN incidents. Procedures and best practice have been developed for collection and sampling of evidence at CBRN crime scenes,[141] and rules of managing chain of custody adapted for CBRN crime scenes.[142] Many EU countries have their own relevant forensic procedures, which in most cases are kept as protected documents unavailable to the public. Therefore, the GIFT CBRN procedures were developed to be as generic as possible to allow a large number of different countries and/or organisations to make use of them.[143]

The European Network of Forensic Science Institutes (ENFSI)

The European Network of Forensic Science Institutes (ENFSI) has also developed a series of Best Practice Manuals (BPMs)[144] with the support of the European Commission. There is a European-wide effort to ensure that all forensic institutes have agreed standards.

The International Organization for Standardization (ISO)

ISO develops standards in close cooperation with national standards bodies. Activities performed on crime scenes and in laboratories are covered by the ISO/IEC 17020[145] and ISO/IEC 17025[24] standards. The ISO/IEC 27037 standards[146] are specific for digital forensic crime scene investigation. The joint EA-ENFSI working group on the quality of crime scene investigations has published a "guidance for the implementation of ISO/IEC 17020 in the field of crime scene investigation"[147] which can be used by crime scene investigation units to develop a quality system.

OPCW Scientific Advisory Board (SAB)

In 2016, the SAB provided advice on best practices related to chemical weapons sample stability and storage in its report "Response to the Director General's Request to the Scientific Advisory Board to Provide Further Advice on Chemical Weapons Sample Stability and Storage".[51]

Scientific Advisory Board of the Office of the Prosecutor of the International Criminal Court (ICC)[148]

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141 Generic Integrated Forensic Tools WP2, O. Claesson, Vahlberg.

142 Generic Integrated Forensic Tools, WP3 (D3.3), D. Benoit, N. Kummer.

143 See for example: "Forensic investigation of incidents involving chemical threat agent: Presentation of the operating procedure developed in Belgium for a field-exercise". N. Kummer, B. Augustyns, D. Van Rompaey, K. De Meulenaere; *Forensic Sci. Int.*; 2019, *299*, 180-186. DOI: 10.1016/j.forsciint.2019.03.037.

144 European Network of Forensic Science Institutes, best practice manuals available at: http://enfsi.eu/documents/best-practice-manuals/.

145 ISO 17020: Conformity Assessment - Requirements for the operation of various types of bodies performing inspection; International Organization for Standardization, ISO/IEC 17020:2012; https://www.iso.org/standard/52994.html.

146 ISO 27037: Information technology — Security techniques — Guidelines for identification, collection, acquisition and preservation of digital evidence; International Organization for Standardization, ISO/IEC 27037:2012; https://www.iso.org/standard/44381.html.

147 "Guidance for the implementation of ISO/IEC 17020 in the field of crime scene investigation", EA-5/03, European Network of Forensic Science Institutes.

148 For further information on the OTP SAB, see (a) paragraphs 11.7 to 11.8 of "Report of the Scientific Advisory Board at its Twenty-Fourth Session" (SAB-24/1, dated 28 October 2016);

Since its establishment in 2014, the Scientific Advisory Board of Office of the Prosecutor of the International Criminal Court has reviewed a variety of R/SOPs in support of the operational forensic investigative activities of the ICC. Two additional SOPs were reviewed in 2018, related to the use of remote sensing evidence and the collection and handling of medical information. This Scientific Advisory Board comprises the President/Chair of broad regional and other forensic societies.

International Network of Environmental Forensics (INEF)

Environmental forensics is the scientific investigation of chemicals in the environment primarily to identify the sources, attribute from where and/or from whom the chemicals may have originated, and to track the environmental fate and any observed adverse effects.[149] To conduct such studies, a significant toolbox of techniques has been developed. The International Network of Environmental Forensics (INEF)[150] has an outreach programme that provides investigators employing environmental forensic techniques with the most current scientific information available.

<u>Technologies and methodologies (whether established or new) that can be used to ensure chain of custody and verification of authenticity (especially in regard to digital images and video recordings)</u>

As outlined in the GIFT CBRN "Procedures and best practice guidelines, describing the rules of managing the chain of custody adapted for CBRN crime scene", all exhibits collected at a crime scene (traditional forensic evidence and CBRN materials) and digital evidence (e.g. raw data extracted from electronic devices, data obtained from analyses) must be relevant to the case, not be at risk of being misplaced or lost, not be at risk of contamination from other sources, and remain intact throughout the entire process.

For a CBRN incident, as with all investigations, exhibits need to be clearly identified, registered and followed to maintain an unbroken chain of custody. The chain of custody is a documented chronological record of custody, control, transfer, analysis, and disposition of evidence (which ca be physical or digital).[151] Maintaining a chain of custody involves the identification, location and registration of each exhibit using a unique number and the use of appropriate packaging and storage conditions to preserve the integrity of the exhibits.

Despite differences between procedures used in individual countries and organizations, the global process to ensure chain of custody is generally based on common practices, such as (a) placing a unique number next to each exhibit collected on the crime scene and recording it by way of photographs, notes, and or sketches; (b) having a list of all exhibits that have been packaged and sealed on a crime scene; and, (c) recording all actions regarding the exhibit (i.e.

www.opcw.org/sites/default/files/documents/SAB/en/sab-24-01_e_.pdf. (b) See paragraph 11.5 to 11.9 of "Report of the Scientific Advisory Board at its Twenty-Sixth Session" (SAB-26/1, dated 20 October 2017); www.opcw.org/sites/default/files/documents/SAB/en/sab-26-01_e_.pdf. (c) See paragraphs 11.1 to 11.3 of SAB-29/WP.2 (referenced in footnote 13(b)). (d) See paragraphs 6.6 to 6.7 of SAB-29/WP.1 (referenced in footnote 13(d)).

149 "Environmental Forensics and the Importance of Source Identification". S. M. Mudge; *Issues in Environmental Science and Technology*; 2008, 26, 1-16. DOI: 10.1039/9781847558343-00001.

150 For further information, see: https://www.rsc.org/Membership/Networking/InterestGroups/INEF/.

151 The United States National Institute of Standards and Technology defines "chain of custody" as: "A process that tracks the movement of evidence through its collection, safeguarding, and analysis lifecycle by documenting each person who handled the evidence, the date/time it was collected or transferred, and the purpose for the transfer". See: https://csrc.nist.gov/glossary/term/chain-of-custody

transport, storage, analyses, destruction). This is to ensure the management and unbroken chain of custody of all exhibits from a CBRN crime scene.

European Union recommendations on the minimum requirements for establishing the full chain of custody of exhibits

All exhibits have to be identifiable during the whole process. This is ensured by giving each exhibit an individual and unique code. When exhibits are segregated in several sub-exhibits (e.g. a DNA swab sampled, a latent fingerprint revealed, and/or raw data extracted from an electronic device), each sub-exhibit has to be identifiable and should be clearly associated with the exhibit from which it was derived.

All information related to an exhibit must be recorded and documented, this includes (a) the sampling during the crime scene investigation (e.g. a description of the exhibit, its location at the crime scene, the date and the time of collection, and the packaging used); (b) all transfers of the exhibit (e.g. the date and time of the transfer, the identity of the person to whom custody of the exhibits was given, and the location where the exhibit is stored; and, all manipulations performed on the exhibit (e.g. decontamination, laboratory examination and analysis, and storage condition and duration).

Adherence to these requirements can be maintained by ensuring the following questions can be answered as part of the R/SOPs being followed:

- **What?** What is the exhibit?
- **When?** When was it collected and used?
- **Who?** Who handled it, and who possesses the exhibit now?
- **Why?** Why was it handled?
- **Where?** Where did it travel to, where was it stored, and where is the exhibit now?
- **How?** How did the investigators obtain the evidence?

Each organisation that has had possession of the exhibit should be able to demonstrate that the exhibit has not been tampered with, changed or substituted; and should be able to provide a description of all manipulations performed on the exhibit; and, the results of all analyses or examinations. Certification and accreditation can help to meet these requirements.

Digital forensics

Digital forensics is the process of uncovering and interpreting electronic data.[45] The goal of the process is to preserve any evidence in its most original form (i.e. not a copy, no matter how exact) while performing a structured investigation by collecting, identifying and validating the digital information for the purpose of reconstructing past events. The ENFSI “Best practice manual for forensic examination of digital technology” provides guidelines for digital evidence.[52]

Digital evidence plays an important role in criminal investigations, as it is used to link persons with criminal activities. Thus, it is of extreme importance to guarantee integrity, authenticity, and auditability of digital evidence as it moves along the different levels of hierarchy in the chain of custody during an investigation.

Distributed ledger technologies (DLT, e.g. “Blockchain)[152] enable access to a comprehensive view of transactions (events/actions) that can be traced back to origination, thus providing enormous promise for the forensic community. DLT that can be leveraged for forensic applications in particular bringing integrity and tamper resistance to digital forensics chain of custody is being developed.[153] DLT, or more specifically a “Blockchain” can be thought of as a series of connected data structures called blocks, which contain or tracks everything that happens on some distributed systems on a peer to peer network. Each block is linked to and depends on previous blocks, thus forming a chain of transactions (blocks) in an append only manner. It provides a permanent and irreversible history that can be used as a real time audit trail by any participant in the chain of transactions to verify the accuracy of the records by simply reviewing the data itself.

<u>Technologies and methodologies (whether established or new) that can be used to ensure the integrity of an investigation site</u>

Ensuring integrity at the site of an investigation begins with restricting access to and securing the site for a forensic examination. Accurately documenting all relevant information related to the site to be investigated, including, but not limited to, photography and ideally 3D imaging[46] (if time and technology allows) is of critical importance.

Digitalisation of an investigation site provides an exact record of the scene at the specific moment in time. This allows investigators to look back at a site and compare it against more recently taken images to ascertain changes that may have taken place since the initial documentation. Generating a digital record of an investigation site can be accomplished using photogrammetry and/or 3D laser scanning. These methods can be used to enhance the speed and accuracy of data collection from an investigation site, as the digitalised records can continue to be examined after the investigation team has left the scene (including by the use of virtual reality tools).

Photogrammetry is a method for data collection where the geometrical properties of an object on site are generated from its photo image. For example, PhotoModeler[154] photogrammetry software is designed to provide accurate measurements and diagramming for many law enforcement, public safety, accident reconstruction and forensic tasks.

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[152] (a) “Blockchain and the future of the internet: a comprehensive review”. F. Hassan, A. Ali, S. Latif, J. Qadir, S. Kanhere, J. Salil, J. Crowcroft; 2019, arXiv:1904.00733. (b) “A review of distributed ledger technologies”. N. El Ioini, C. Pahl; in H. Panetto, C. Debruyne, H. Proper, C. Ardagna, D. Roman, R. Meersman (eds), *On the Move to Meaningful Internet Systems. OTM 2018 Conferences. OTM 2018. Lecture Notes in Computer Science, 11230.* Springer, Cham, 2018. DOI: 10.1007/978-3-030-02671-4_16. (c) “Distributed Ledger Technology and Blockchain”. H. Natarajan, S. Krause, H. Gradstein; World Bank, 2017; https://elibrary.worldbank.org/doi/abs/10.1596/29053.

[153] (a) “Tamper-evident timestamped provenance ledger using Blockchain technology?”. D.-O. Jaquet-Chiffelle, E. Casey, J. Bourquenoud; Preprint submitted to *FSI Digital Investigation*, January 2020. (b) “Blockchain for modern digital forensics: the chain-of-custody as a distributed ledger”. H. Al-Khateeb G. Epiphaniou, H. Daly; in: H. Jahankhani, S. Kendzierskyj, A. Jamal, G. Epiphaniou, H. Al-Khateeb (eds), *Blockchain and Clinical Trial. Advanced Sciences and Technologies for Security Applications*, Springer, Cham, 2019. DOI: 10.1007/978-3-030-11289-9_7. (c) “Blockchain solutions for forensic evidence preservation in IoT environments”. S. Brotsis, N. Kolokotronis, K. Limniotis, S. Shiaeles, D. Kavallieros, E. Bellini, C. Pavue; arXiv:1903.10770, 2019.

[154] For further information, see: https://www.photomodeler.com/pm-applications/pub-safety-forensics/.

Forensic applications of 3D laser scanning and photogrammetry include:

- Reconstructing and creating diagrams of crime scenes.[155]

- Extracting measurements (such as height or placement) from surveillance videos (also surveillance video applications pages).

- Determining a bullet's 3D trajectory (allowing the point source to be determined).[156] As well as scanning a bullet's striking surface to aid ballistics analysis.

- 3D scanning a footprint in sand or soil, allowing comparison to the corresponding shoe.[157]

- 3D scanning of tire mark allowing comparison to the corresponding tire.[158]

- Creating orthophotos (photos with no perspective distortion) of fluid spills or blood spatter.[159]

- 3D scans of body surfaces for bite marks.[160]

- Determining positions of vehicles, cranes, and/or building failures in photographs taken prior to an accident.

3D laser scanning is the process of analysing objects, buildings and outdoor locations to collect data on the shape and possibly appearance (e.g. colour). The collected data can then be used to construct a digital model. 3D laser scanning is widely used by the law enforcement agencies around the world. These tools are useful in accident reconstruction, investigations of bombings[161] and for producing retrievable digital records for preservation of art and architecture.[162]

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155 (a) "Enhancing forensic investigation through the use of modern three-dimensional (3D) imaging technologies for crime scene reconstruction". D. Raneri; *Aus. J. Forensic Sci.*; 2018, *50(6)*, 697-707, DOI: 10.1080/00450618.2018.1424245. (b) "A toolbox for the rapid prototyping of crime scene reconstructions in virtual reality". T. Sieberth, A. Dobay, R. Affolter, L. Ebert; *Forensic Sci. Int.*; 2019, *305*, 110006. DOI: 10.1016/j.forsciint.2019.110006.

156 For example: "Accuracy and reproducibility of bullet trajectories in FARO Zone 3D". E. Liscio, Q. Le, H. Guryn; *J. Forensic Sci.*; 2020, 65(1), 214-220. DOI : 10.1111/1556-4029.14144.

157 For example: "A new method for the recovery and evidential comparison of footwear impressions using 3D structured light scanning". T. J. U. Thompson, P. Norris; *Science & Justice*, 2018, *58(3)*, 237-243. DOI : 10.1016/j.scijus.2018.02.001.

158 For example: "What happened before the run over? Morphometric 3D reconstruction". U. Buck, K. Buße, L. Campana, F. Gummel, C. Schyma, C. Jackowski; Forensic Sci. Int.; 2020, 306. DOI: 10.1016/j.forsciint.2019.110059.

159 For example: "Improved area of origin estimation for bloodstain pattern analysis using 3D scanning". O. Esaias, G. Noonan, S. Everist, M. Roberts, C. Thompson, M. Krosch; *J. Forensic Sci.*; 2019; online publication DOI: 10.1111/1556-4029.14250.

160 For example: "A new method to geometrically represent bite marks in human skin for comparison with the suspected dentition". B. Ramos, J. C. Torres, A. Molina, S. Martin-de-las-Heras; *Aus. J. Forensic Sci.*; 2019, *51(2)*, 220-230. DOI: 10.1080/00450618.2017.1356869.

161 For example: "3D reconstructions of a controlled bus bombing". C. Villa, N. F. Hansen, K. M. Hansen, H. P. Hougen, C. Jacobsen; *J. Forensic Rad. Imaging*; 2018, *12*, 11-20. DOI: 10.1016/j.jofri.2018.02.004.

162 For example: "A review of recording technologies for digital fabrication in heritage conservation". A. Weigert, A. Dhanda, J. Cano, C. Bayod, S, Fai, M. Quintero, M.; *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*; 2019, *XLII-2/W9*. 773-778. DOI: 10.5194/isprs-archives-XLII-2-W9-773-2019.

Recommendations of Sub-group D

Recommendation: *The Secretariat should ensure that forensic issues are included in R/SOPs and Working Instructions including those related to on-site sample collection, handling, curation and storage, and annotation in accordance with forensic best practices.*[20]

> For investigations that may provide information suggesting a violation of the Convention, it is critical to ensure that the information used to draw any conclusion is able to meet internationally accepted standards. R/SOPs should be regularly reviewed and updated.

Recommendation: *Consider how to best make use of suitable electronic evidence tracking technologies, which can be attached to, or packed with evidence/samples at the point of collection and followed electronically.*

> IoT devices that can record information on the handling and integrity of a packaged samples are an area to consider. Combinations of these tracking devices such as, Trace Identification Number [Spoor Identificatie Nummer (SIN)[22]]), and the Comprehensive Test Ban Treaty/Onsite Inspection (CTBT/OSI) sample tracking system[23] can provide added capabilities for ensuring chain of custody. Distributed ledger technology (DLT/blockchain) should also be considered.

Recommendation: *Make use of technologies that allow digitalised documentation of investigation scenes and sites.*

> These technologies include UAVs and UGVs, photogrammetry and/or 3D scanning systems (which can be used individually or in combination). These tools and methods provide capabilities to provide real time images of an investigation site prior to entry and during a forensic investigation. Data collected in this manner would provide information on the risks present at the site prior to entry, guide the development of sampling strategies, and provide digitalised documentation of the incident site at the moment it was examined. The latter enables detailed examination of a scene to continue beyond the time an inspection team can be physically present, as well as providing benefits for chain-of-custody purposes.

Sub-group E: Provenancing

Sub-group E was tasked to address provenance, with focus on the questions from sub-paragraphs 4(f) and 4(j) of the TWG's TOR, which are:

- Which technologies and methodologies (whether established or new) can be used in provenancing of chemical and/or material samples collected in an investigation?

- Do collections of physical objects, samples, and other information for chemical weapons-related analysis exist and can they be made available to investigators for retrospective review? How might these collections be used to support investigations?

The sub-group looked at five priority areas to address the assigned questions:

- Coordination with and encouragement of laboratories to be more actively engaged with the CFITWG.[18]

- Identification of others whose work relies heavily on provenancing (for example, scientists involved in food authentication and in oil spill forensics).

- Review of protocols of others, including the tools and methods used (IRMS,[163] SNIF-NMR,[164] and inorganic analysis, for example).

- Chemical forensic analysis in biological samples (including human, animal, and plants).

- Exploration of the feasibility of access to data from past chemical weapon investigations for the review of the scientific approaches and results.

Provenancing or source profiling of a chemical warfare agent could in principle be achievable through the examination of extrinsic chemical signatures such as impurities or additives (both organic and inorganic)[165] and intrinsic chemical signatures such as stable isotope ratios and isomeric ratios.[166] There are two typical cases envisioned based on the scenario of a chemical incident: matching of two (or more) samples with a suspected common origin, and provenancing of chemical warfare agent samples from a single source.

Sample matching is a frequently used in forensic investigations for linking together events and seized materials. Chemical profiling approaches are used. Some of the analytical tools already implemented for analysis of chemical warfare agents (e.g. GC-MS and LC-MS) are well suited for chemical profiling, as they can detect extrinsic chemical signatures.[66(a)] The

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163 For example: IRMS = Isotope-ratio mass spectrometry. See for example: "Forensic applications of isotope ratio mass spectrometry – A review". S. Benson, C. Lennard, P. Maynard, C. Roux; *Forensic Sci. Int.*; 2006, *157*, 1-22. DOI: 10.1016/j.forsciint.2005.03.012.

164 For example: (a) "Enhanced forensic discrimination of pollutants by position-specific isotope analysis using ratio monitoring by ^{13}C magnetic resonance spectrometry". M. Julien, P. Nun, P. Höhener, J. Parinet, R. J. Robins, G. S. Remaud; *Talanta*; 2016, *147*, 383-389. DOI : 10.1016/j.talanta.2015.10.010. (b) "The application of NMR and MS methods for detection of adulteration of wine, fruit juices, and olive oil. a review". N. Ogrinc, I. J. Kosir, J. E. Spangenberg, J. Kidric;, *Anal. Bioanal. Chem.;* 2003, *376*, 424-430. DOI: 10.1007/s00216-003-1804-6.

165 For example: (a) "Organic chemical attribution signatures for the sourcing of a mustard agent and its starting materials". C. G. Fraga, K. Bronk, B. P. Deockendorff, A. Heredia-Langner; *Anal. Chem.*; 2016, *88*, 5406-2413. DOI: 0.1021/acs.analchem.6b00766. (b) "Source attribution of cyanides using anionic impurity profiling, stable isotope ratios, trace element analysis and chemometrics". N. S. Mirjankar, C. G. Fraga, A. J. Carman, J. J. Moran; *Anal. Chem.*; 2016, 88, 1827-1834. DOI: 10.1021/acs.analchem.5b04126. (c) "Impurity profiling to match a nerve agent to its precursor source for chemical forensics applications". C. G. Fraga, G. A. Pérez Acosta, M. D. Crenshaw, K. Wallace, G. M. Mong, H. A. Coulburn; *Anal. Chem.*; 2011, *83*, 9564-9572. DOI: 10.1021/ac202340u. (d) "Synthesis route attribution of sulfur mustard by multivariative data analysis of chemical signatures". K. H. Holmgren, S. Hok, R. Magnusson, A. Larsson, C. Åstot, C. Koester, D. Mew, A. K. Vu, A. Alcaraz, A. M. Williams, R. Norlin, D. Wiktelius; *Talanta;* 2018, *186*, 615-621. DOI: 10.1016/j.talanta.2018.02.100.

166 For example: (a) "TATP isotope ratios as influenced by worldwide acetone variation". J. D. Howa, J. E. Barnette, L. A. Chesson, M. J. Lott, J. R. Ehleringer; *Talanta;* 2018, *181*, 125-131. DOI: 10.1016/j.talanta.2018.01.001. (b) "Stable carbon and nitrogen isotope ratios of sodium and potassium cyanide as a forensic signature". H. W. Kreuzer, J. Horita, J. J. Moran, B. A. Tomkins, D. B. Janszen, A. Carman; *J. Forensic Sci.;* 2012, *57(1)*, 75-79. DOI: 10.1111/j.1556-4029.2011.01946.x.

signatures of interest could include contaminants and traces of starting materials in the sample; and, by-products from the route of synthesis as well as stabilizers and other components added during the production/preparation process of the chemical warfare agent. Additionally, there are methods for acquisition of intrinsic chemical signatures,[167] such as stable isotope ratios for selected elements present in chemical warfare agents.

Interpretation of results benefits from knowledge of common chemical markers for the specific chemical warfare agent of interest, and the process of matching generally requires samples to be comparable in concentration and matrix (e.g. the comparison of samples with neat substances). For these reasons, it is difficult establish linkages between different types of samples (i.e. a highly concentrated sample of the neat substance and an environmental sample collected at the site of an incident) based on the comparison of their chemical profiles.

Chemical markers present in trace amounts in a concentrated sample may not be detectable in the environmental sample, and differences in sample matrices may produce interferences that make comparisons difficult. The lack of a match in chemical profiles can be used to infer that samples do not have a common source, but the assessment of a match is more critical. Without knowledge of the common variation in relevant chemical profiles, it is difficult to determine the significance of a linkage. To allow such an assessment, there is a need for reference data based on samples of the chemical agents of different origins describing the expected variation in chemical profiles.

Provenancing of a sample from a single event looks for information that can identify the probable origin of the sample, its production method, storage and handling conditions, and any other signatures of its life cycle. For this situation, there is an urgent need to have access to reference data that would allow for the linkage of the suspect sample to synthesis route, specific starting materials, and level of technical competence of the producer. The reference data must be comprehensive; unfortunately, the availability of such data for chemical warfare agents is very limited.

Chemical profiling reference data of samples with known provenance (production route, starting material for synthesis etc.) would be useful to include in a chemical profiling database. The data could include all chemical signatures to be used for provenancing.

Successful applications of provenancing of chemical samples, including retrospective determination of production method, and where the profiling methods are used for sample matching can be found in the analysis of drugs of abuse[168] and explosives,[169] and also in

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167 For example: "Stable-carbon isotope ratios for sourcing the nerve-agent precursor methylphosphonic dichloride and its products". J. J. Mora, C. G. Fraga, M. K. Nims; Talanta, 2018, 186, 678-683. DOI: 10.1016/j.talanta.2018.04.021. (b) "Measurement and analysis of disastereomer ratios for forensic characterization of brodifacoum". J. R. Cort, P. J. Alperin, H. Cho. Measurement and analysis of disastereomer ratios for forensic characterization of brodifacoum"; Forensic Sci Int.; 2012, 214, 178-181. DOI: 10.1016/j.forsciint.2011.08.003.

168 For example: (a) "A review of recent advances in impurity profiling of illicit MDMA samples". R. J. H. Waddell-Smith; *J. Forensic Sci;* 2007, 52(6), 1297-1304. DOI: 10.1111/j.1556-4029.2007.00559.x (b) "The analytical and chemometric procedures used to profile illicit drug seizures". N. Daéid, R. J. H. Waddell; *Talanta;* 2005, *67*, 280-285. DOI: 10.1016/j.talanta.2005.05.018.

169 For example: (a) "Carbon and nitrogen isotope ratios of factory-produced RDX and HMX". J. D. Howa, M. J. Lott, L. A. Chesson, J. R. Ehleringer; *Forensic Sci. Int.*, 2014, *240*, 80-87. DOI: 10.1016/j.forsciint.2014.04.013. (b) "Sourcing explosives: A multi-isotope approach". D. Widory, J.J. Minet, M. Barbe-Leborgne; *Sci. Justice*, 2009, *49*, 62-72. DOI: 10.1016/j.scijus.2008.11.001

environmental forensics,[170] where chemical analysis results have been transferred to a legal process. Engagement with experts from these fields would benefit the development of provenance capabilities for chemical warfare agents. Engagement with the CFITWG is valuable to keep abreast of developments in the field.

Recommendations of Sub-group E

Recommendation: *Consider establishing a new TWG on the provenancing of samples of chemicals relevant to the Convention.*

Discussions should bring together SAB members, representatives of Designated Laboratories, and other experts in chemical forensics and profiling. Chemical profiling of samples to enable determination of their provenance requires analytical and data analysis approaches, and reference data that differ from those being currently employed by the Designated Laboratory Network for off-site verification analysis. The TWG would consider inter alia requirements for method development, and inter-laboratory chemical profiling exercises, standardisation and evaluation.

Recommendation: *The OPCW Laboratory should consider developing an OPCW chemical profiling database for raw instrumental data (e.g. GC/MS data) for the composition of samples of chemical threat agents of known provenance, including but not limited to additives, synthetic impurities and degradation products.*

Previously collected data on chemical threat agent samples could be added to the database and used for testing approaches to chemical profiling.

Recommendation: *Explore the possibilities for retrospective mining of previously collected data on authentic samples containing signatures of chemical threat agents.*

If permission can be obtained, such exercises would be useful for developing reference data that includes validated chemical signature information.

Recommendation: *Encourage the Secretariat and Designated Laboratory network to engage with, and where possible participate in projects of, the CFITWG.*

The CFITWG is a forum for the development of peer-reviewed chemical profiling approaches and the exchange on information that is suited to the provenance determination on chemical warfare agents and related compounds, which is a developing field of science.

Recommendation: *Publish scientific results obtained from the development of chemical profiling methods in peer-reviewed scientific literature.*

Peer-reviewed scientific publications demonstrate validity and robustness of methods and enable data comparison. They are viewed worldwide as important validations for investigative mechanisms.

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170 For example: "Objective chemical fingerprinting of oil spills by partial least-squares discriminant analysis". M. P. Gómez-Carracedo, J. Ferré, J. M. Andrade, R. Fernández-Varela, R. Boqué; *Anal. Bioanal. Chem.;* 2012, *403*, 2027-2037. DOI: 10.1007/s00216-012-6008-5. (b) "Atmospheric polycyclic aromatic hydrocarbons: source attribution, emission factors and regulation". K. Ravindra, R. Sokhi, R. Van Grieken; *Atm. Env.*, 2008, *42(13)*, 2895-2921. DOI: 10.1016/j.atmosenv.2007.12.010.

Recommendation: *Encourage laboratories analysing authentic samples containing signatures of chemical threat agents to publish their results in peer-reviewed scientific journals, to enable additional validation of the methods and approaches, and to enhance overall the capability of the Designated Laboratory network.*

> Reports of provenance determination on chemical warfare agent samples are especially relevant for validating the methods being developed in this developing field of science. They are also vital for providing standards against which any allegations of chemical weapons use in future can be compared, to increase the probability of finding concrete linkages between events in the past and those in the future. This is important for the identification of linkages between multiple events of alleged chemical weapon use

Recommendation: *Engage and share experiences with experts in other fields who perform chemical forensic analysis.*

> Relevant sectors include (but are not limited to) environmental forensics, food adulteration and illegal drug enforcement.

Sub-group F: Methodologies, procedures, technologies and equipment

Sub-group F was tasked to address additional considerations, with focus on TOR paragraph 5, providing advice on Secretariat proposals for methodologies, procedures, technologies and equipment for investigative purposes.

The sub-group looked at four priority areas to address the assigned questions:

- Consideration of non-traditional options for data collection.
- Consideration of where traditional best practices may not fit the situational needs in the environments, and under the scenarios, where inspectors may be operating.
- Consideration of how to increase and improve the sustainability of field missions.
- Understanding factors related to technical investigative assistance, including possible legal issues.

Under the June 2018 CSP decision, the Secretariat has been directed to identify those involved in the use of chemical weapons in Syria. Attribution, i.e. the determination of responsibility for the use of chemicals or other actions prohibited by the Convention, is in the end a judgement drawing on a wide range of technical data and other kinds of information. Technical procedures, for example, chemical analyses that link traces of material found in a sample to a source are extremely valuable but are only one of many inputs into an attribution determination. Seldom will sample analysis alone be sufficient for a determination of responsibility.

In contrast to routine inspection missions, non-routine fact-finding and investigation missions may be conducted under conditions that are unfamiliar, hard-to-predict, physically difficult and dangerous. Inspectors may not be able to visit the site of an incident or to meet with affected individuals, because locations are too remote and access is physically not possible or because the physical security or health of inspectors would be placed at too great a risk. Thus, alternative means of collecting information, other than through direct physical access to a site, need to be identified, assessed and implemented. For example, analysis of high-resolution satellite imagery from commercial sources has already demonstrated its value in OPCW fact-finding efforts, and in other arms control and non-proliferation contexts. Historical commercial satellite imagery, which is frequently available,[171] can be used to assess activities at a site over time, for example, before, during and after an alleged incident. The extensive civil use of UAVs to obtain imagery of sites that are difficult to access or to assess hazards at a potentially dangerous site[172] provides another example of technology that could be utilized for non-routine OPCW missions. Video conferencing tools with encryption capabilities should also be considered for interviewing.

Although inspectors may not be able to visit a site, host government personnel, local inhabitants or other civilians may have access to a site and thus be able to collect relevant information. Information collected by non-OPCW personnel, however, is most useful if the OPCW can be confident that it knows precisely where the information was collected, under what conditions, and by whom, and also that the information has not been altered or tampered. By creatively adapting existing technology, the OPCW has already made use of non-OPCW personnel to collect information in a few cases.[173] A good example is the use of sealed, GPS-enabled video cameras, furnished by the OPCW and operated by Syrian government personnel, to monitor destruction activities in the Syrian Arab Republic at dangerous locations.[174] The TWG recognises the availability of guidelines and mobile device applications, such as *eyeWitness to atrocities*[175] that are designed to assist the general public to document and collect evidence. These types of information-gathering tools are expected to become more prevalent.[176] As long as proper safeguards are established, such tools and procedures could materially assist an investigation.

The problem of direct access to the site of an incident or to affected individuals is particularly acute with respect to collection of environmental and biomedical samples for off-site laboratory analysis. Lacking access, OPCW fact-finding efforts have necessarily had to rely on samples collected by non-OPCW personnel. Creative pairing of several different technologies, however, might allow samples to be collected from a site by non-OPCW

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171 For example: (a) M. Hanham, J. Lewis, C. Dill, G. Liu, J. Rodgers, O. Lepinard, B. Knapp, O. Hallam, B. McIntosh; "Geo4Nonpro 2.0", *CNS Occasional paper #38*, Middlebury Institute of International Studies at Monterey, James Martin Center for Nonproliferation Studies, 2018; https://www.nonproliferation.org/op38-geo4nonpro-2-0/. (b) G. Liu, J. Rodgers, S. Milne, M. Rowland, B. McIntosh, M. Best, O. Lepinard, M. Hanham; "Eyes on U: Opportunities, Challenges, and Limits of Remote Sensing for Monitoring Uranium Mining and Milling", CNS Occasional paper #44, Middlebury Institute of International Studies at Monterey, James Martin Center for Nonproliferation Studies, 2018; https://www.nonproliferation.org/op-44-eyes-on-u-opportunities-challenges-and-limits-of-remote-sensing-for-monitoring-uranium-mining-and-milling/.

172 (a) See paragraphs 12.7 to 12.8 of SAB-28/WP.2 (referenced in footnote 13(b) (b) See paragraphs 10.3 to 10.5 and 13.1 to 13.11 of SAB-28/WP.3 (referenced in footnote 13(c)).

173 See for example, paragraphs 10.1 to 10.2 of SAB-28/WP.3 (referenced in footnote 13(c)).

174 "Progress in the Elimination of the Syrian Chemical Weapons Programme" (EC-75/DG.6, dated 25 February 2014); www.opcw.org/sites/default/files/documents/EC/75/en/ec75dg06_e_.pdf.

175 For further information, see: (a) https://www.eyewitnessproject.org/. (b) See paragraphs 8.8 to 8.10 of SAB-28/WP.3 (referenced in footnote 13(c)).

176 See for example: (a) The Human Rights Investigations Lab; https://www.law.berkeley.edu/research/human-rights-center/programs/technology/human-rights-investigations-lab-internships/. (b) *New project: Digital evidence, blockchain, and air-strikes in Yemen*, 16 March 2018, Global Legal Action Network; https://www.glanlaw.org/single-post/2018/03/15/New-project-Digital-evidence-blockchain-and-air-strikes-in-Yemen.

personnel and then transferred to OPCW custody while still meeting high forensic standards for ensuring chain-of-custody. Smartphone applications already exist that could assist in documenting the collection of samples.[175,176,177] Simple UAVs that are already in an operational testing phase have range and cargo capabilities that could enable the retrieval of samples from a remote site.[178] The Secretariat should explore how such technologies could be adapted and combined to solve the vexing issue of site access. In this connection, the OPCW should support work to develop simple methods for secure packaging and sealing of samples, using commonly available materials, that could be used in such situations.

Increasingly, information potentially relevant to a non-routine mission is available from open sources such as social media, YouTube videos and other information; or electronic documents or samples provided by interested parties. Before this information can be relied upon, its authenticity needs to be established. Extensive expertise in assessing such information, for example, using metadata associated with videos, or forensic analysis of digital files, already exists in the law enforcement community.[45] The Secretariat should continue to strengthen its working relationships with sources of such expertise.

OPCW R/SOPs have been developed for situations where the circumstances are generally well-defined and predictable. Experience has shown, however, that non-routine missions may involve situations where the parameters for on-site activity are impossible to predict in advance and may be highly constrained. Inspectors may have little time to prepare for a visit to a site, have only a short time there, and be very limited in the type or quantity of equipment they can bring to it.[36] Such situations put a high premium on obtaining as much information as possible in advance for the planning of a visit, having a capability to extract the maximum amount of information from the site quickly, and having equipment that is simple, versatile, and easy to transport and use. Current and former OPCW personnel who have been involved in non-routine missions are a critical source of advice about the capabilities that are needed. They are a unique and highly valuable resource. The Secretariat should make a concerted and continuing effort to involve such current and former inspectors in developing investigative procedures and identifying and assessing equipment for non-routine missions.[179] The effort should involve field evaluation in relevant training scenarios.

Non-routine missions, which may last much longer than routine missions and may also take place in tense and dangerous environments, impose new demands on the sustainability of field teams. In addition to the physical tasks associated with housing, logistics and communications over an extended term, non-routine missions may place inspectors under considerable physical and mental stress, both during the mission and afterwards. The OPCW's ability to maintain an effective investigative capability may well rest on dealing effectively with these issues. Again, the Secretariat should make a concerted and continuing effort to involve current and former OPCW inspectors experienced in non-routine missions to identify potential difficulties associated with the sustainability of non-routine missions and effective ways of addressing them. Particular attention should be paid by the Secretariat to the mental well-being of inspectors during a mission and afterwards.

One new type of non-routine mission, providing technical investigative assistance to a State

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177 See paragraphs 8.8 to 8.10 of SAB-28/WP.3 (referenced in footnote 13(c)

178 (a) *Unmanned Aerial Vehicles Landscape Analysis: Applications in the Development Context*, USAID Global Health Supply Chain Program, 2017; https://www.ghsupplychain.org/sites/default/files/2017-06/GHSC_PSM_UAV%20Analysis_final.pdf. (b) *Unmanned Aerial Vehicle Procurement Guide: Specifications, Questions and Other Criteria to Consider*, USAID Global Health Supply Chain Program, 2018; https://www.ictworks.org/wp-content/uploads/2018/10/usaid-UAV-buying-guide.pdf.

179 See paragraphs 10.6 to 8.10.7 of SAB-28/WP.3 (referenced in footnote 13(c)).

Party, poses unique and highly complex technical, forensic, and legal issues, since it could result in OPCW personnel becoming involved in a process leading to domestic or international criminal prosecution. An example would be a case of suspected chemical terrorism. Among the issues that need to be carefully explored in advance are the following: What specifically would OPCW personnel be authorized to do? Would OPCW personnel directly carry out investigative tasks or only advise host State personnel? What restrictions would be placed on the activities of the OPCW personnel, either by the Director-General or the host State? To what extent would the activities of the OPCW personnel be subject to review in the host State's legal process? (For example, how would the Director-General handle a summons for OPCW personnel to testify in a domestic criminal proceeding, which might involve severe penalties or even execution?). If the host State requested that samples be analysed in OPCW Designated Laboratories, what would be the practical and legal ramifications for those laboratories? The Secretariat should identify and carefully explore technical, forensic, and legal issues involved in providing technical investigative assistance to a State Party and inform Member States of the findings.

As noted throughout this report, equipment and procedures that are potentially relevant to the conduct of a non-routine OPCW mission are being developed for many other applications, including law enforcement, hazardous material monitoring and chemical defence. The Secretariat will need to systematically monitor technical developments and consider how they could be used to further strengthen OPCW verification capabilities. Priority should be given to tools that would allow rapid and efficient on-site information gathering, providing the greatest amount of information under time constrained and potentially non-permissive operating environments. SAB reports will continue to provide information on technologies of potential value,[38,40,42] however the Secretariat will benefit the most from taking a more active role by conducting a modest technology evaluation and adaptation programme, financed through the regular budget. This in-house effort could be supplemented by a systematic technical support programme by Member States to meet requirements defined by the OPCW. Such a function would usefully include field evaluation in relevant training scenarios. The technology support programme conducted by IAEA and its Member States provides a relevant international model.[180]

Recommendations of Sub-group F

the Secretariat should:

Recommendation: *Identify and evaluate alternative means of collecting as much relevant information as possible about an incident site in advance of direct physical access, including the use of UAVs or commercial satellite imagery.*

> This would help to maximise safety, security and effectiveness of on-site activity. This effort should include developing procedures and equipment through which non-OPCW personnel who have access can be used to collect and transfer information in a forensically sound manner.

180 (a) Research and Development Plan: Enhancing Capabilities for Nuclear Verification, IAEA Safeguards STR-385, 2018; https://www.bnl.gov/ISPO/docs/STR-385-IAEA-Department-of-Safeguards-RD-Plan.pdf. (b) "Development and Implementation Support Programme for Nuclear Verification 2018 – 2019", IAEA Safeguards STR-386, 2018: https://www.iaea.org/sites/default/files/18/09/sg-str-386-development-support-programme.pdf. (c) the IAEA has also used crowd-sourcing approaches to gain access to new capabilities, for further information, see https://challenge.iaea.org/challenges/all.

Recommendation: *For situations where OPCW personnel cannot access a sampling site, develop procedures and equipment for non-OPCW personnel to collect environmental or biomedical samples, and transfer them to OPCW.*

> This would help to ensure integrity of samples and allow verification of authenticity of samples provided to the OPCW. Such procedures can make use of digital tools and technologies that are being developed and deployed for collection of verifiable information unaltered from its original form, substantiated by time stamps and geolocation data.

Recommendation: *Continue to strengthen working relationships with communities of expertise for identifying relevant open-source information and evaluating its authenticity, particularly for digital information.*

Recommendation: *Make a concerted and continuing effort to engage current and former OPCW personnel who have participated in non-routine missions in improving the Secretariat's investigative capability.*

> Involve these personnel in developing investigative procedures and equipment, and in the evaluation of training scenarios in preparation for future missions. Engage these personnel in identifying potential difficulties associated with the sustainability of non-routine missions and effective ways of addressing them. Attention should be paid to issues such as post-traumatic stress.

Recommendation: *Strengthen the ability to evaluate and adopt new technologies and equipment to meet the Secretariat's evolving needs.*

> Efforts can be put forth that involve both internal processes and voluntary assistance from Member States. Conduct a modest technology evaluation and adaptation programme, financed through the regular budget, to take advantage of equipment and procedures being developed in other contexts. Establish a programme for technical support conducted by Member States (this could follow the model of the IAEA).

Recommendation: *Identify and carefully explore technical, forensic, and legal issues involved in providing technical investigative assistance to a State Party and inform Member States of the findings.*

> Assisting a State Party may require different operating procedures than are used in investigations conducted by the OPCW.

Recommendation: *Consider incorporation of end user requirements, such as reporting on technical information, into mission planning and operating procedures when conducting a mission that might transfer information to other entities. Information collected on-site by inspectors and/or generated through off-site analysis may potentially be transferred to others for further review.*

> If the transferred information is to be subjected to further evaluation (in particular, if it were to be reviewed under a legal framework which could require individuals involved in the investigation to justify their approaches), suitability of the methods and approaches to meet the needs of the evaluators must be considered.

Glossary

Full Term	Definition
Antibody	A protective protein produced by the immune system in response to the presence of a foreign substance (an "antigen").
Aqueous samples	Samples prepared in and/or dissolved in water.
Article IX	The article of the Chemical Weapons Convention that addresses consultations, cooperation, and fact-finding (www.opcw.org/chemical-weapons-convention/articles/article-ix-consultations-cooperation-and-fact-finding).
Article VIII	The article of the Chemical Weapons Convention that addresses the organisation (www.opcw.org/chemical-weapons-convention/articles/article-viii-organization).
Attribution	The determination of responsibility for an action.
Article X	The article of the Chemical Weapons Convention that addresses assistance and protection against chemical weapons. (www.opcw.org/chemical-weapons-convention/articles/article-x-assistance-and-protection-against-chemical-weapons).
Biological and Toxins Weapons Convention (BTWC)	The Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological and Toxin Weapons and on their Destruction (https://www.unog.ch/80256EE600585943/(httpPages)/77CF2516DDC5DCF5C1257E520032EF67?OpenDocument).
Bioluminescence	The emission of light by a biochemical process.
Blockchain	A distributed ledger technology that functions as a record of transactions which is created by linking through cryptography. Each transaction is a "block" containing a cryptographic record of the previous block and associated timestamp and transaction data.
Case file	A collection of documents and evidence relating to a specific investigation.
Chemical Biological Radiological Nuclear (CBRN)	Chemical, biological, radiological and/or nuclear materials that could be used to cause harm by accidental or deliberate release, dissemination or impacts.
Chemical forensics	Obtaining information from traces and signatures found within chemical remnants that is relevant to investigative questions.
Chemical profile	Chemical and/or elemental signatures, which can be used to obtain information about the potential source of a chemical sample and/or its method of synthesis. The profile includes by-products, impurities, and unreacted starting materials found in the sample.
Chemical threat agent	A chemical with potential for us as a chemical weapon.
Chemical warfare agent	The toxic chemical component of a chemical weapon.
CFITWG	Chemical Forensics International Technical Working Group
Challenge inspection (CI)	An inspection designed to clarify and resolve any questions concerning possible non-compliance. See Article IX of the Chemical Weapons Convention and Part X of its Verification Annex.
Chain-of-custody	The documented record of acquisitions, transfers, handling and disposition of physical or electronic materials.
Colorimetry	The determination of coloured compounds (in a solution) in by measuring absorbance of a specific wavelength of light.
The Conference of the States Parties of the Chemical Weapons Convention (CSP)	The principal and plenary organ of the OPCW which oversees the implementation of the Chemical Weapons Convention, promotes its goals, and reviews compliance with the treaty. It also oversees the activities of the Executive Council and Technical Secretariat (www.opcw.org/about-us/conference-states-parties).
Comprehensive Nuclear Test Ban Treaty Organisation (CTBTO)	The organisation that oversees the Comprehensive Nuclear-Test-Ban Treaty (CTBT). As this treaty is not yet in force, the CTBTO exists as a Preparatory Commission (https://www.ctbto.org/).

Full Term	Definition
Declarations Assessment Team (DAT)	Established in 2014 to engage the relevant Syrian authorities to resolve the identified gaps and inconsistencies in the Syrian declaration (www.opcw.org/declaration-assessment-team).
Detection	The ability to detect the presence of a chemical.
Digitalisation	The process of converting information into digital (i.e. computer-readable) format.
Distributed Ledger Technology (DLT)	A consensus of replicated, shared, and synchronized digital data stored across multiple locations. In the context of this report, represents a Blockchain (see also) that exists as a distributed ledger.
Designated Laboratory	Laboratories designated by the OPCW for the analysis of authentic samples. Designated Laboratories must be able to perform off-site analysis of chemical samples collected by OPCW inspectors from chemical production facilities, storage depots, and other installations, or from the site of an alleged use of chemical weapons, and provide forensic proof if a violation of the Convention has occurred.
Electrophilic addition	A chemical reaction where an "electrophile" adds to a double or a triple bond resulting in breaking of a π bond and the formation of new σ bonds.
Enzyme-Linked Immunoassay (ELISA)	A technique that uses antibodies linked to enzymes to detect and measure the amount of a substance. Capture antibodies are immobilised on a solid surface which a target analyte binds to. In the final step, an enzymatic reaction takes place that initiates a measurable colour change that is used as a readout signal for determination of the concentration of the analyte.
European Network of Forensic Science Institutes (ENFSI)	A network of experts is to share knowledge, exchange experiences and come to mutual agreements in the field of forensic science (http://enfsi.eu/about-enfsi/).
EuroBioTox	The European programme for the establishment of validated procedures for the detection and identification of biological toxins. This is an EU funded project from 2017 - 2022 that is integrating 61 laboratories from 23 States Parties (www.eurobiotox.eu).
Executive Council (EC)	A Council of 41 OPCW Member States that are elected by the Conference of the States Parties and rotate every two years. The Council supervises the activities of the Technical Secretariat and is responsible for promoting the effective implementation of and compliance with the Chemical Weapons Convention (www.opcw.org/about-us/executive-council).
Exhibit	A document or object presented as evidence obtained during an investigation.
False negative	A test result which wrongly indicates that a particular condition or attribute is absent.
False positive	A test result which wrongly indicates that a particular condition or attribute is present
Fact-Finding Mission (FFM)	An OPCW mission that was set up in 2014 "to establish facts surrounding allegations of the use of toxic chemicals, reportedly chlorine, for hostile purposes in the Syrian Arab Republic" (www.opcw.org/fact-finding-mission).
Flame photometry detection (FPD)	The use of a detector that measures characteristic chemiluminescent emission from specific chemical species formed in a reducing flame.
Forensic chemistry	Chemistry used for forensic purposes.
Forensic intelligence	The extension of the forensic case-by-case approach (i.e. evidential focus) into a more phenomenological and proactive approach. Its role is not solely limited to investigations or to confirm hypotheses suggested by conventional investigative means, but also to proactively provide insights into investigated activities and to support the elicitation of relevant hypotheses.[44]
Forensic science	The science used for forensic purposes.
Forensics	Relating to or denoting the application of scientific methods and techniques to an investigation.

Full Term	Definition
Fourier Transform Infrared Spectroscopy (FTIR)	An analytical technique used to generate infrared spectra (absorption or emission) of chemical sample (which can be solid, liquid or a gas). An FTIR spectrometer simultaneously collects data over a wide spectral range.
Gas chromatography (GC)	Method used to identify presence of chemicals where volatile chemicals are carried through a column that separates them from one another in the gas phase (often used together with mass spectrometry: GC-MS).
High molecular weight (HMW) toxin	In this report, this terminology is used to refer to biological toxins that exist as large protein-based molecules (for example) ricin and botulinum).[181]
Identification	The ability to identify a specific chemical from other chemicals.
International Atomic Energy Agency (IAEA)	An intergovernmental organisation that serves as a forum for scientific and technical co-operation in the nuclear field. The Agency works for the safe, secure and peaceful uses of nuclear science and technology. For further information see www.iaea.org.
Investigation of alleged use (IAU)	An investigation, requested by a State Party, that serves to establish facts related to an alleged use of a chemical weapon, and provides a basis upon which the Executive Council can take a decision with regard to whether or not to instruct the Secretariat to take further action to assist the requesting State Party. See Article IX of the Chemical Weapons Convention and Part X of its Verification Annex.
International Criminal Court (ICC)	An intergovernmental organisation and international tribunal that investigates and, where warranted, tries individuals charged with the gravest crimes of concern to the international community: genocide, war crimes, crimes against humanity and the crime of aggression (https://www.icc-cpi.int/about).
International Impartial and Independent Mechanism (IIIM)	An international organisation that collects and analyses information and evidence of international crimes committed in Syria since March 2011 to assist criminal proceedings in national, regional or international courts or tribunals that have or may in the future have jurisdiction over these crimes (https://iiim.un.org/mandate/#).
Investigation and Identification Team (IIT)	Established under paragraph 10 of C-SS-4/DEC.3, the IIT is responsible for identifying the perpetrators of the use of chemical weapons in the Syrian Arab Republic by identifying and reporting on all information potentially relevant to the origin of those chemical weapons in those instances in which the Fact-Finding Mission (see also) determines or has determined that use or likely use occurred, and cases for which the OPCW-UN Joint Investigative Mechanism did not issue a report (see also, www.opcw.org/media-centre/featured-topics/decision-addressing-threat-chemical-weapons-use).
Immunoassay	A procedure for detecting or measuring specific analytes (“antigens”) by antibodies.
Information Management System	A system designed to facilitate the storage, organization and retrieval of information.
Internet-of-things (IoT)	A system of interrelated devices that transfer data over a network.
International organisation (IO)	An 'organisation established by a treaty or other instrument governed by international law.
Ion mobility spectrometry (IMS)	An analytical method that separates ions in gaseous phase based on the differences of their mobilities under an electric field. The differences in mobility can be used to detection chemicals of interest.
International Organization for Standardization (ISO)	An international standard-setting body composed of representatives from various national standards organizations. For further information see www.iso.org.
Liquid chromatography (LC)	Method used to identify presence of chemicals where volatile chemicals are carried through a column that separates them from one another in the liquid phase (often used together with mass spectrometry: GC-MS).

181 For examples of the diversity of forms that toxins can take, see: www.opcw.org/sites/default/files/documents/Science_Technology/Biological_Toxins_and_their_Relative_Toxicity_.pdf.

Full Term	Definition
Lateral flow assay (LFA)	Paper-based devices intended to detect the presence of a target analyte in liquid sample.
Low molecular weight (LMW) toxin	In this report, this terminology is used to refer to biological toxins that would be considered organic chemicals (for example, saxitoxin or strychnine).
Mass spectrometry (MS)	Method used to identify presence of chemicals (often used together with gas chromatography, e.g. GC-MS).
Nerve agents	Chemicals that disrupt the mechanisms by which nerves transfer signals across the central nervous system through the inhibition of acetylcholinesterase.
Newly scheduled agent	Chemicals added to the Schedules of the Chemical Weapons Convention through an amendment process after the entry-into-force of the Convention. As of 31 December 2019, only two such proposals to add chemicals to the Schedules had been adopted since entry-into-force in 1997.
Non-governmental organisation (NGO)	An organisation that is neither a part of a government nor a conventional for-profit business.
Non-routine mission	An OPCW mission that does not follow modalities and operating procedures set out explicitly in the Chemical Weapons Convention.
OPCW Central Analytical Database (OCAD)	A reference library of analytical data. It contains validated spectroscopic and chromatographic data of chemicals of relevance to the Convention. Its primary purpose is to enable onsite analysis during OPCW inspections.
Off-site analysis	A chemical analysis that takes place away from the site at which the sample was collected.
On-site analysis	A chemical analysis that takes place at the site at which the sample was collected.
Polymerase chain reaction	A method of making multiple copies of a DNA sequence, involving repeated reactions with a polymerase.
Photoionisation Detector (PID)	A detector that uses an ultraviolet (UV) light source to ionize chemicals to gas phase molecules.
Point-of-care	An on-site measurement made at the exact location where a sample is found. The terminology is commonly used in a clinical setting to indicate a measurement made directly on a patient in their hospital room/bed.
Point-of-need	An on-site measurement made at the exact location where a sample is found. This terminology is intended to avoid confusion that may arise when using the terminology "point-of-care" in a non-clinical application.
Provenance	The chronology of ownership, custody and/or location.
Rapid Response and Assistance Mission (RRAM)	An OPCW mission that can be deployed upon request of a State Party to the Chemical Weapons Convention in need of urgent assistance due to a chemical weapons attack (see also, www.opcw.org/our-work/responding-use-chemical-weapons).
Raman Spectroscopy	A chemical analysis technique that provides information on chemical structure by measuring vibrational modes of molecules.
Review Conference	A conference of States Parties convened to review the operation of the Chemical Weapons Convention. Review Conferences have been convened in five-year intervals, since the First Review Conference in 2003. The most recent, Fourth Review Conference was held in 2018. For further information on the Fourth Review Conference, see: www.opcw.org/resources/documents/conference-states-parties/fourth-review-conference.
RefBio	Germany's Contribution to Strengthen the Reference Laboratories Bio in the UNSGM. This is a German Federal Foreign Office funded project running from 2017 – 2022 to support evaluating methodologies and laboratories under the UNSGM.
Radio-frequency identification (RFID)	The use of electromagnetic or electrostatic coupling in the radio frequency portion of the electromagnetic spectrum to uniquely identify an object.

Full Term	Definition
Recommended and/or standard operating procedure (R/SOPs)	An ROP is a recommended method to be followed for the performance of designated operations or in designated situations. This differs from aa SOP which is an established or prescribed method to be that is followed routinely for its designated purpose.
Scientific Advisory Board (SAB)	A subsidiary body of the OPCW established in accordance with article VIII of the Convention to enable the Director-General of the OPCW to render specialised advice in science and technology to Member States. The SAB comprises 25 independent experts (see also www.opcw.org/about-us/subsidiary-bodies/scientific-advisory-board).
Selectivity	The extent to which a method can determine particular analytes in mixtures or matrices without interferences from other components. See https://old.iupac.org/projects/posters01/vessman01.pdf).
Sensitivity	A measure of the ability of an analytical method to establish the that differences in the amount of analyte measured between individual samples is are significant. This is different than the method's detection limit, which is the smallest amount of analyte that can be determined with confidence.
Service level agreement (SLA)	An agreed upon commitment between a service provider and a service user (e.g. a "client").
Surface Plasmon Resonance (SPR)	An optical technique used for detecting molecular interactions. SPR occurs on electron-rich metal surfaces (such as gold) upon impact of an incident light of a specific frequency. SPR analysis methods are used to detect changes in refractive index on the surface due interactions (binding, adsoprtion) between molecules bound to surface and molecules that come in contact with the surface.
State Party	Member State of the OPCW; a state which has acceded to (is a "Party" to) the Chemical Weapons Convention
Technical assistance visit (TAV)	Upon request, the Technical Secretariat will visit a State Party that does not seek an investigation or a rapid response in order to provide advice and assistance (see also, www.opcw.org/our-work/responding-use-chemical-weapons).
Toxic industrial chemical	Industrial chemicals, that can potentially be used in a harmful way, that are manufactured, stored, transported, and used throughout the world.
Toxin (biological toxin)	A poisonous substance that is a specific product of the metabolic activities of a living organism. Toxins can be small molecules, peptides, or proteins that exert their toxic effects through interaction with biological macromolecules such as enzymes or cellular receptors.
Temporary working group (TWG)	A working group established under the Scientific Advisory Board to consider issues in depth for a time limited period.
Unmanned aerial vehicle (UAV)	An aerial vehicle piloted by remote control or onboard computers. In this report, UAV references are made to small, portable copter and/or fixed wing remote controlled aircraft or "drones".
Unmanned ground vehicle (UGV)	A vehicle that is operated by remote control or onboard computers while in contact with the ground and without an onboard human presence.
United Nations	An international organisation formed in 1945 to increase political and economic cooperation among its member countries (www.un.org).
United Nations Secretary-General's Mechanism (UNSGM)	A mechanism under the United Nations Secretary-General, to undertake timely and evidence-based investigations (missions) in response to allegations involving the use of chemical, bacteriological (biological) or toxin-based weapons.

Annexes

Annex 1: Terms of Reference

1. The Technical Secretariat's (hereinafter "the Secretariat") on-going contingency operations have increasingly involved investigations and fact-finding, with collection and evaluation of oral, material and digital evidence of the use of chemical agents; activities that are not part of routine Chemical Weapons Convention inspection and verification. The Director-General has decided that an in-depth review of how and when methods and technologies used in investigative work would be relevant to the Secretariat. He has asked the Scientific Advisory Board (SAB) to conduct this review. Further to his response to the report from the Twenty-Fourth Session of the SAB (SAB-24/1 dated 28 October 2016), and in accordance with paragraph 9 of the terms of reference of the SAB, the Director-General has therefore established a Temporary Working Group (TWG) on Investigative Science and Technology and has appointed Dr Veronica Borrett as the Chairperson of the group.

2. The objective of the TWG is to review science and technology relevant to investigative work, especially for the validation and provenancing (determining the chronology of ownership, custody and/or location) of evidence, and the integration of multiple and diverse inputs to reconstruct a past event. This would also include further considerations of topics in the recommendations from the SAB's 2016 chemical forensics workshop (SAB-24/WP.1, dated 14 July 2016), and topics falling under subparagraphs 2(e)[182] and 2(g)[183] of the SAB's terms of reference. The work of this TWG is intended to identify capabilities, skill sets and equipment that would augment and strengthen the Secretariat's investigative capabilities. The findings will be considered by the SAB and recommendations provided to the Director-General.

3. The TWG will consist of individuals who collectively have expertise in theory and practice of investigative work; including but not limited to investigational chemical analysis, evidence collection, forensic sciences, informatics, crime scene reconstruction, toxicology, inspection or experience of implementation of the Chemical Weapons Convention. Qualified members of the SAB may join the TWG. Members of relevant scientific organisations and international organisations may also be invited to join the TWG. Guest speakers may be invited from time to time. The TWG may also, when necessary, draw upon the expertise of the Secretariat; in particular the OPCW Laboratory, Inspectorate, and the Assistance and Protection Branch.

4. Reporting to the SAB, the TWG will in particular consider the following questions:

   (a) Which methods and capabilities used in the forensic sciences could usefully be developed and/or adopted for Chemical Weapons Convention-based investigations?

   (b) What are the best practices and analysis tools used in the forensic sciences for effectively cross-referencing, validating, and linking together information related to investigation sites, materials collected/analysed and individuals interviewed?

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182 "… assess the scientific and technological merit of a present, or proposed, methodology for use by the Technical Secretariat in verification under the Convention".

183 "... assess and report on emerging technologies and new equipment which could be used on verification activities".

(c) What are the best practices for management of data collected in investigations, including compilation, curation, and analytics?

(d) What are the best practices for the collection, handling, curation and storage, and annotation of evidence?

(e) Which technologies and methodologies (whether established or new) allow point-of-care and non-destructive measurements at an investigation site to help guide evidence collection?

(f) Which technologies and methodologies (whether established or new) can be used in provenancing of chemical and/or material samples collected in an investigation?

(g) Which methods are available (or are being developed) for the sampling and analysis of environmental and biomedical materials that can be used in the detection of toxic industrial chemicals relevant to the Convention?

(h) Which technologies and methodologies (whether established or new) can be used in ensuring chain of custody and verifying authenticity (especially in regard to digital images and video recordings)?

(i) Which technologies and methodologies (whether established or new) can be used to ensure the integrity of an investigation site?

(j) Do collections of physical objects, samples, and other information for chemical weapons relevant analysis exist that can be made available to investigators for retrospective review? And how might these collections be used to support investigations?

(k) Are there stakeholders that the Secretariat could usefully engage with, to leverage their capabilities on investigative matters?

5. In addition, the TWG will provide advice on the Secretariat's proposals for methodologies, procedures, technologies, and equipment for investigative purposes.

6. The Director-General might pose other relevant questions to the TWG, through the SAB.

7. The TWG will exist for a period of two years from the date of its first meeting. Thereafter its work will be reviewed by the SAB and the Director-General, and a decision will be made as to whether it should continue its work, and, if so, whether the terms of reference should be revised.

Annex 2: Reports and Briefings of the Temporary Working Group on Investigative Science and Technology

Date Issued	Document	Available at
26 February 2018	"Summary of the First Meeting of the Scientific Advisory Board's Temporary Working Group on Investigative Science and Technology" (SAB-27/WP.1)	www.opcw.org/sites/default/files/documents/SAB/en/sab-27-wp01_e_.pdf
23 November 2018	Presentation by TWG Chairperson at the Fourth Review Conference (as part of a side event jointly organised with the Spiez Laboratory)	www.opcw.org/sites/default/files/documents/2018/12/20181123-Science_for_Diplomats_at_RC4-Convergence%20and%20solving%20chemcial%20mysteries.pdf
21 January 2019	"Summary of the Second Meeting of the Scientific Advisory Board's Temporary Working Group on Investigative Science and Technology" (SAB-28/WP.2)	www.opcw.org/sites/default/files/documents/2019/01/sab28wp02%28e%29.pdf
4 June 2019	"Summary of the Third Meeting of the Scientific Advisory Board's Temporary Working Group on Investigative Science and Technology" (SAB-28/WP.3)	www.opcw.org/sites/default/files/documents/2019/06/sab-28-wp03%28e%29.pdf
25 November 2019	"Summary of the Fourth Meeting of the Scientific Advisory Board's Temporary Working Group on Investigative Science and Technology" (SAB-29/WP.1)	www.opcw.org/sites/default/files/documents/2019/11/sab-29-wp01%28e%29.pdf

Annex 3: Members of the Temporary Working Group on Investigative Science and Technology

Member	Affiliation
Dr Crister Åstot	Swedish Defence Research Agency (FOI), Umeå, Sweden
Dr Augustin Baulig	Secrétariat général de la défense et de la sécurité nationale, Paris, France
Dr Veronica Borrett[184]	La Trobe Institute for Agriculture and Food, Melbourne, Australia
Dr Christophe Curty[185]	Spiez Laboratory, Switzerland
Dr Brigitte Dorner	Robert Koch Institute, Berlin, Germany
Dr Carlos Fraga	Pacific Northwest National Laboratory, Richland, Washington, United States of America
Professor David Gonzalez	Department of Chemistry, University of the Republic of Uruguay and Ministry of Education, Montevideo, Uruguay
Dr Robert Mikulak	Department of State, Washington, DC, United States of America
Dr Daan Noort	TNO, Rijswijk, the Netherlands
Dr Syed K. Raza	Chairperson Accreditation Committee, National Accreditation Board for Testing and Calibration Laboratories (NABL), India
Mr Valentin Rubaylo	State Scientific Research Institute of Organic Chemistry and Technology, Moscow, Russian Federation
Mr Cheng Tang[186]	Office for the Disposal of Japanese Abandoned Chemical Weapons, Ministry of National Defence, China

184 Chairperson of the TWG.
185 2019 Vice-Chairperson/2020 Chairperson of the SAB.
186 2019 Chairperson of the SAB.

Member	Affiliation
Dr Christopher Timperley[187]	Defence Science and Technology Laboratory (Dstl), Porton Down, United Kingdom of Great Britain and Northern Ireland
Mr Francois Mauritz van Straten	Independent former Scientific Advisory Board member, South Africa
Drs Ed van Zalen[188]	Netherlands Forensic Institute (NFI), The Netherlands
Professor Paula Vanninen	University of Helsinki and VERIFIN, Helsinki, Finland
Ms Farhat Waqar	Pakistan Atomic Energy Commission

Annex 4: Guest Speakers at Meetings of the Temporary Working Group on Investigative Science and Technology

Speaker	Affiliation
First Meeting	
Ms Anna Davey	Forensic Foundations™, Australia
Mr Marko Milivojevic	Regional Forensic Division, Ministry of Interior, Novi Sad, Republic of Serbia
Mr Stefan Mogl	Spiez Laboratory, Switzerland
Mr Lennie Phillips	Consultant
Dr Zhenwen Sun	Institute of Forensic Science, Beijing, China
Mr Steven Wallis	Consultant
Second Meeting	
Mr Lars Bromley	United Nations Institute for Training and Research, Division for Satellite Analysis and Applied Research, New York, United States of America
Dr Eoghan Casey	University of Lausanne, Switzerland
Ms Hoe-Chee Chua	DSO National Laboratories, Singapore. Member of the OPCW Scientific Advisory Board October 2017 to September 2019
Dr Sven-Eric Jordt	Duke University School of Medicine, Durham, North Carolina, United States of America
Mr Thiago Piwowarczyk	New York Art Forensics, Brooklyn, United States of America
Mr Günter Povoden**	EU CBRN Centres of Excellence Initiative, Austria. Appointed to the OPCW Scientific Advisory Board in 2019.
Professor Kevin Thomas	The University of Queensland, Brisbane, Australia
Third Meeting	
Ms Wendy Betts	eyeWitness to Atrocities, London, United Kingdom
Mr Scott Dubin	Contractor USAID Global Health Supply Chain Program Procurement and Supply Management, Washington DC, United States of America
Ms Doris Eerhart	Netherlands Forensic Institute (NFI), the Netherlands
Dr Geoff Gordon	Global Legal Action Network and T. M. C. Asser Institute, The Hague, the Netherlands
Dr Olli Heinonen	Foundation for Defence of Democracies, Washington, DC, United States of America
Professor Ralf Kaiser	University of Glasgow and Lynkeos Technology Ltd, United Kingdom
Ms Grace Liu	James Martin Center for Nonproliferation Studies, Monterey, California, United States of America
Ms Irene O'Sullivan	Netherlands Forensic Institute (NFI), the Netherlands
Professor Michael Madden	National University of Ireland Galway
Dr Didier Meuwly	Netherlands Forensic Institute (NFI), the Netherlands
Dr Subramanian Raja	Centre for Chemical Weapons Analysis, Malaysia
Professor Åke Sellström	Umeå University, Sweden
Mr Rolf Ypma	Netherlands Forensic Institute (NFI), the Netherlands
Mr Leo Zaal	Netherlands Forensic Institute (NFI), the Netherlands

187 2015-2018 Chairperson of the SAB.
188 Vice-Chairperson of the TWG.

Speaker	Affiliation
Fourth Meeting	
Ms Hoe-Chee Chua*	DSO National Laboratories, Singapore. Member of the OPCW Scientific Advisory Board October 2017 to September 2019
Ms Doris Eerhart	Netherlands Forensic Institute, the Netherlands
Mr Florian Käding	Prometech B.V., Utrecht, the Netherlands
Dr Klaus Mayer	European Commission, Joint Research Centre, Karlsruhe, Germany
Mr Scott McKenzie	SensaData, Melbourne, Australia
Dr Stephan Mudge	Norwegian Institute for Air Research, Oslo, Norway
Mr George Psarras	T4i Engineering, Loughborough, United Kingdom of Great Britain and Northern Ireland
Mr Mark Ramon Redeker	Expert Team Visualisation and Reconstruction (ETVR) of the Dutch National Police Force. Police, Central Unit, DLOS, Central Forensic Service Centre, Driebergen, the Netherlands
Mr Yue Jin Tay	Circulor, London, United Kingdom of Great Britain and Northern Ireland
Mr Jos Tóth	Netherlands Forensic Institute, the Netherlands
Mr Gert Wijnalda	Prometech B.V., Utrecht, the Netherlands
Dr Marcel van der Schans	TNO, the Netherlands
Dr Dion Varrosieau	Netherlands Forensic Institute, the Netherlands
Mr Toine Voeten	Expert Team Visualisation and Reconstruction (ETVR) of the Dutch National Police Force Police. Central Unit, DLOS, Central Forensic Service Centre, Driebergen, the Netherlands
Fifth Meeting	
Ms Doris Eerhart	Netherlands Forensic Institute, the Netherlands
Dr Tina Kauppila	University of Helsinki and VERIFIN, Helsinki, Finland
Mr Antti Vaaras	Finnish Ministry of Foreign Affairs, Finland

Acknowledgements

The Temporary Working Group on Investigative Science and technology publishes this report in memory of Mr Valentin Rubaylo who passed away in June 2019. Mr Rubaylo, a member of the TWG, and also the SAB since 2014, had also served on the SAB's TWG on Verification. He was one of the first Chemical Demilitarisation Officers to be appointed to the Secretariat at the time of the entry-into-force of the Convention. Valentin Rubaylo, a colleague, a friend, and a scientist, will be dearly missed.

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