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Strengthening the norms against chemical and biological weapons

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Chemical and microbiological forensics in investigations of alleged uses of chemical and biological weapons – a preliminary analysis

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Executive Summary

- Allegations of the use of chemical and biological weapons can be investigated under the Chemical Weapons Convention, and through the UN Secretary General's Mechanism. Other investigation mechanisms may also be employed, for example in the context of human rights law or war crimes investigations, but when it comes to scientific expertise and resources, the systems set up by the OPCW and available to the UNSGM are the most relevant today.
- Such investigations set out to determine whether a chemical or biological weapon has been used, what the agent has been, how severe the impact of the attack has been, and what the origin of the weapons was. In recent years, investigations have been mandated to gather information that allows to identify perpetrators of such acts. This creates a link between arms control law (focusing on State compliance), and criminal law (dealing with the responsibility of individuals and legal entities).
- The call for attribution has spurred scientific work that extends beyond analytical methods developed in the past. Several countries as well as the OPCW and the United Nations are making efforts to build capacity in chemical and microbiological forensics for investigation purposes.
- The OPCW has established a trusted and still expanding network of designated laboratories to support such investigations. Experience is growing with regard to employing these capabilities for attribution purposes. In the biological field, efforts are under way to develop an international network of qualified and trusted laboratories to support UNSGM investigations. The status of this network is gradually changing from vision to reality.
- Significant scientific challenges remain, including with regard to the scope of analysis, validation of methods, certified reference materials, curated databases and repositories, agreed acceptance criteria for unambiguous identification, methods for distinguishing natural from deliberate events, and for the investigation of provenance. Actual investigations will remain complex, scientifically challenging, and time consuming.
- Continuing attention of and investment by governments into these efforts will be essential to make further progress. At the same time, the interface between arms control and disarmament treaties and mechanisms on the one hand, and human rights and criminal law on the other, should be more clearly defined.

1. Introduction

Forensic science is generally understood to mean the application of science to the law.[1] It can be employed to investigate a wide range of crimes, including war crimes. Chemical and microbial forensics focus specifically on investigating the malicious use of hazardous chemicals and microbiological agents. This makes these disciplines relevant to the investigation of violations of the norm against chemical and biological weapons, and their use in particular.

The use of chemical weapons in Syria, assassination attempts using chemical agents developed in past chemical weapons programmes, and terrorist incidents involving the preparation for and in some cases actual use of toxic chemicals as weapons have led to efforts to enhance international and national investigative and forensic capabilities to identify those responsible for these acts.

This paper looks at the legal, political and institutional context for such investigations at the international level, provides an overview of the state of the art in chemical and microbial forensics, and identifies issues that may require additional study or action.

2. Background

Investigations of allegations of the use of chemical or biological weapons are fact-finding mechanisms to clarify the circumstances of what might have been a grave violation of the norm prohibiting the use of chemical or biological weapons. To deal with possible violations of the norm against chemical weapons, the 1997 Chemical Weapons Convention (CWC) establishes an elaborate system of compliance management and fact-finding, including investigations of the alleged use of chemicals weapons.[2] These procedures have been devised to help States Parties resolve compliance concerns based on verified factual evidence,[3] and if necessary, take measures to enforce compliance including by imposing sanctions on the party that has violated the norm.[4]

The 1975 Biological Weapons Convention (BWC) does not contain a verification system similar to the CWC. Instead, a State Party suspecting a violation may take the matter to the Security Council,[5] or it may call for a Formal Consultative Meeting (FCM) of the BWC States Parties.[6] These are political/ diplomatic processes rather than technical fact-finding measures. They will usually rely on evidence and assessments presented by the parties to a non-compliance dispute and other actors concerned.[7] Such clarification attempts may, however, lead to decisions about *ad hoc* fact-finding measures to strengthen the evidence base of a case.

Complementing the mechanisms available under these disarmament treaties is the UN Secretary-General's Mechanism established in 1987 by the UN General Assembly.[8] It gives the Secretary-

[1] Wolstenhome, R., Jickells, S. and S. Forbes, *Analytical techniques in forensic science*, Wiley & Sons 2021, p.7.
[2] Of particular relevance are the provisions of Articles VIII, IX and X, and of the Verification Annex Parts X and XI.
[3] Trapp, R., *Compliance management under the Chemical Weapons Convention*. UNIDIR WMD Compliance and Enforcement Series Paper 3, UNIDIR 2019.
[4] Trapp, R. and Tang, C., *Enhancing the management and enforcement of compliance in the regime prohibiting chemical weapons*, UNIDIR WMD Compliance and Enforcement Series Paper 12, UNIDIR 2021.
[5] BWC Article VI.
[6] This procedure implements Article V of the BWC on consultation and cooperation among States parties to resolve problems relating to the objectives of, or in application of the provisions of, the BWC.
[7] See for example the documents of the FCM called by the Russian Federation in 2022 regarding its claims of US violations of the BWC by funding bioweapons facilities in the Ukraine, available at https://meetings.unoda.org/meeting/65052/documents .
[8] Other international organisations such as the WHO, the FAO and the WOAH may also investigate such situations. However, they focus on managing the impact of a disease outbreak and controlling the propagation

General authority to carry out investigations of the reported use of chemical, bacteriological (biological) or toxin weapons that may constitute a violation of the 1925 Geneva Protocol or other relevant rules of customary international law.[9] Guidelines and Procedures[10] for such investigations were endorsed by the General Assembly in 1990.[11] The technical appendices of these Guidelines and Procedures were updated in 2006.[12] The UNSGM remains, as of today, the only international mechanism explicitly mandated to investigate allegations of the use of biological weapons.

Reports of the use of chemical weapons in 2013 in Syria prompted such UNSGM investigation, which confirmed several cases of chemical weapons uses.[13] After Syria's accession to the CWC in 2013 and despite joint efforts of the United Nations and the OPCW to eliminate Syrian chemical weapons, incidents of the use of toxic chemicals as weapons were again reported beginning in the spring of 2014. In response, the Director-General of the OPCW set up a Fact-Finding Mission to investigate these reports.[14] Neither of these mechanisms was mandated to collect information regarding the responsibility for any CW uses. To fill this gap, the UN Security Council established in 2015 the UN-OPCW Joint Investigative Mechanism (JIM) to "identify to the greatest extent feasible individuals, entities, groups, or governments who were perpetrators, organisers, sponsors or otherwise involved in the use of chemicals as weapons ...in the Syrian Arab Republic...".[15] The JIM reported several times on its findings,[16] and identified the Syrian government as well as the Islamic State as entities responsible for some of these chemical attacks. Its mandate was extended once, but due to Russian opposition to the JIM finding the Syrian government responsible for some of the attacks, it had to be closed down in November 2017.[17]

In response to the increasing number of chemical weapons uses in recent years, the OPCW adopted in 2018 a decision on addressing the threat from chemical weapons use,[18] which amongst others led to the establishment of the OPCW Investigation and Identification Team (IIT).

The IIT was set up to gather information that would allow to identify perpetrators of chemical weapons uses in Syria. The decision also authorises the Technical Secretariat to provide technical assistance to States Parties investigating possible chemical weapons uses on their territory, and to share information with investigative entities established by the United Nations General.

of the disease. Identifying the perpetrators of a deliberate attack would go beyond the mandate and competence of these organisations.

[9] United Nations General Assembly: Resolution A/Res/42/37 (1987). This mechanism was endorsed by the Security Council in August 1988 (United Nations Security Council: Resolution 620 (1988).

[10] United Nations Document A/44/561 (1989), including Annex I and Appendices I through IX, and Annex II.

[11] United Nations General Assembly: Resolution A/RES/45/58 (1990).

[12] United Nations General Assembly: Resolution 60/288 (2006).

[13] This UN mission was supported by the OPCW and the WHO. First report at https://digitallibrary.un.org/record/756814?ln=en , second and final report at https://digitallibrary.un.org/record/762282?ln=en .

[14] The legal basis of establishing the FFM was explained a Note by the OPCW Technical Secretariat, *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, paragraphs 1-4 of Annex 2, 16 June 2014.

[15] Security Council, S/RES/2235, 7 August 2015, https://undocs.org/S/RES/2235(2015), operative paragraph 5.

[16] Its seventh and last report was published on 26 October 2017, as UN document S/2017/904.

[17] For a brief summary of the end of the JIM, see for example Trapp and Tang (2021), op. cit., p. 15.

[18] OPCW document C-SS-4/Dec.3 of 27 June 2018. The decision was adopted by vote (82 in favour, 24 against; see OPCW document C-SS-4/3, 3.15).

These developments in arms control and disarmament proceeded alongside efforts in the field of international criminal law.

Although the negotiators of the Rome Statute failed to incorporate the use of chemical and biological weapons into the International Criminal Court's jurisdiction over war crimes, they *did* include the employment of poison or poisoned weapons, as well as of asphyxiating, poisonous or other gases, and all analogous liquids, materials or devices.[19] This language mirrors provisions of previous instruments of international humanitarian law, and includes most if not all weapons today considered to meet the definition of a "chemical weapon" under the CWC.[20,21] However, the precise scope of what is covered under the Rome Statute remains contentious and has not been tested in the Court. Furthermore, ICC investigation and prosecution with regard to countries that are not parties to the Rome Statutes would require a referral by the UN Security Council.[22]

Also important are developments in the context of human rights law.

After the Human Rights Council established the Independent International Commission of Inquiry on the Syrian Arab Republic in August 2011[23], the UN General Assembly in December 2016 decided to set up the "International, Impartial and Independent Mechanism to Assist in the Investigation and Prosecution of Persons Responsible for the Most Serious Crimes under International Law Committed in the Syrian Arab Republic since March 2011" (IIIM).[24] Both bodies have looked at cases of chemical weapons use. The IIIM is making use of evidence gathered by the Syria Commission of Inquiry as well as the OPCW's FFM and IIT.[25] Whilst none of these bodies has the quality of an international tribunal or prosecutorial body, they are mandated to collect and preserve evidence of serious human rights violations in the Syrian conflict. The IIIM has a mandate to share information and evidence collected and analytical work produced with national, regional and international prosecution services and courts.[26] Absent international tribunals dealing with these violations at this point in time, this opens an avenue of prosecution under national penal laws enacted by States in accordance with the requirements of the CWC and the BWC,[27] including where national legislation allows for universal jurisdiction. This approach has also been adopted by the International Partnership Against Impunity for the Use of Chemical Weapons launched in Paris in January 2013. Its participants gather, compile, retain and facilitate the sharing of information so that perpetrators can eventually be held accountable.[28]

[19] Rome Statute of the International Criminal Court, United Nations, Treaty Series, vol. 2187, No. 38544.Art. 8.2.b(xiii),(xiv) and b(xiii),(xiv).
[20] See Dapo Akande "Can the ICC prosecute the use of chemical weapons in Syria" EJIL:Talk! Blog of the European Journal of International Law (23 August 2013) at https://www.ejiltalk.org/can-the-icc-prosecute-for-use-of-chemical-weapons-in-syria/
[21] Alex Whiting "The International Criminal Court, the Islamic State, and Chemical Weapons", Just Security (4 November 2015), https://www.justsecurity.org/27359/icc-islamic-state-chemical-weapons/
[22] Rome Statute Article 13(b).
[23] Human Rights Council 17th Session, resolution S-17/1 (22 August 2011).
[24] UN General Assembly Resolution A/Res/71/248 adopted by vote (105 in favour, 15 against, 52 abstentions) on 21 December 2016.
[25] A memorandum of understanding between he OPCW and the IIIM was signed in 2018 to enable the cooperation between the two bodies. See OPCW document EC-89/DG.29 (4 October 2018)
[26] For details on the nature of this assistance and its limitations see https://iiim.un.org/what-we-do/support-to-jurisdictions/
[27] Article VII.1 of the CWC requires each State Party to enact penal legislation to prohibit natural and legal persons on its territory or in any other place under its jurisdiction from undertaking any activity prohibited to a State Party, not to permit such acts in any place under its control, and to extend its penal legislation to acts committed by its nationals anywhere. BWC Article IV requires States parties to "prohibit and prevent" acts prohibited to a party in its territory and elsewhere under its jurisdiction or control.
[28] The Partnership has today 40 States and the EU as its partners. For details see https://www.noimpunitychemicalweapons.org/-en-.html

These developments combine the traditional compliance management approach of arms control with efforts to identify and prosecute individuals and legal entities involved in the preparation and conduct of attacks with chemical or biological weapons. Compliance management aims at generating confidence of States Parties that the benefits of respecting treaty obligations outweigh the costs of violation. It increases transparency in order to reduce misperceptions of the behaviour of other States Parties and to enable *bona fide* parties to demonstrate their compliance.[29]

The increasing emphasis on criminalisation of the use of chemical and biological weapons can be interpreted as a recognition that this norm is universally recognised today – hence, violations must not be tolerated.

It also reflects concerns that uses of these weapons might undermine the norm. Nationally, States can respond to these pressures by adapting and enforcing their penal laws. Internationally, States can support mechanisms that gather evidence of such violations and make them available for legal proceedings. But to be able to do so, alleged use investigations need to be able to conform to the standards applied in such legal proceedings.

3. Investigating an alleged use of a chemical or biological weapon

The goal of an alleged use investigation is to gather, verify and report evidence pertaining to (an) incident(s) of a possible use of a chemical or biological weapon, as well as to present scientific and technical evaluations of how this body of evidence supports or refutes the hypothesis that a chemical (biological, toxin) weapon has been used. Depending on the request that triggered the investigation and the context, this may range from confirming or refuting that a chemical (biological, toxin) weapon has been used to identifying the perpetrators for such an attack.

An investigation will test conflicting hypothesis about the nature of an incident, and report its findings in ways that allow policy makers and lawyers to address issues of (non-)compliance as well as responsibility for any attack confirmed.

It does so by using procedures and methods of evidence collection, preservation, management, protection and analysis that are based on commonly accepted scientific and procedural standards. An investigation report must demonstrate that readers can trust the validity, authenticity, and integrity of the evidence reported, the integrity and independence of the investigation process, and the scientific soundness of the methods used.

Technically speaking, an investigation attempts to reconstruct an incident in a given context, space and time. To this end, it uses all information available, including situational and contextual data. It will gather evidence relevant to the alleged incident, and weigh each piece of evidence against criteria such as how confident investigators can be that it was authentic and had not been tampered with or degraded, how relevant it is to understand and demonstrate what had actually happened, how robust and transparent the methods are that were used to interrogate the evidence, and how confident technical assessments are based on the methods and materials used.

The procedural and methodological frameworks for such investigations are set out, respectively, in Part XI of the CWC Verification Annex and the UNSGM Procedures and Guidelines. Both focus on the presumed victims and locations of the alleged CBW attack.[30] They direct investigators to:

- inspect, assess and collect evidence from the site(s) of the presumed attack(s)
- interview and medically examine alleged victims
- interview eye witnesses

[29] Marauhn, T. “Article IX: Consultation, cooperation and. Fact-finding”, in Krutzsch, W, Myjer, E., and R. Trapp (Eds.), *The Chemical Weapons Convention – A Commentary*, OUP 2014, p. 328.
[30] See for example CWC Verification Annex Part XI.15, which requires access to be given to “any and all areas affected by the alleged use of chemical weapons” and “hospitals, refugee camps and other locations it [the inspection team] deems relevant for the effective investigation of the alleged use of chemical weapons”.

- interview as well as review documentary evidence from medical staff and hospital administrators involved in the treatment of victims.

These methodologies are based on experiences from UN investigations conducted during the 1980ies. The central questions to answer were: had chemical or biological weapons actually been used? What was the nature of the attack? Which agent(s) were used? In addition, investigators were tasked to secure and report any information that might help establishing the origin of the weapons, for example by identifying impurities or other relevant substances in samples.[31]

When investigations are requested to gather information that may lead to attributing responsibility for crimes committed, care needs to be taken to clarify precisely what the question(s) are that the investigators are requested to answer. What does "origin" mean in the context of a particular investigation? What does that entail with regard to the information and evidence sought? It is important to remember that the OPCW and the UNSGM are not judicial investigating bodies. They lack authority to gather evidence in the same manner as prosecutorial offices, courts, and tribunals, and do not have authority and jurisdiction to issue judicial determinations or other legally binding verdicts on criminal responsibility.[32]

The scope of such investigations will inevitably extend beyond the alleged incident site. To gather evidence leading to attribution, in particular, investigators will need to look at additional locations, actors and activities that were associated with the alleged use.

This may include data regarding military aircraft flights, activities of (para)military units outside of the incident area, information about the lines of command and control, intercepted communications between units directly or indirectly involved in the alleged incident, politico-military information on higher-level chains of command and decision-making authority, and other relevant data.

An example is the investigation methodology adopted by the OPCW IIT. The IIT described in some detail the information types and sources it considered: information received from the FFM; answers to specific questions received from States Parties including Syria; witness statements previously recorded as well as interviews conducted in its own investigation; videos, documents and other materials from various sources; analytical results and other scientific assessments from OPCW Designated Laboratories and other forensic laboratories and experts; satellite imagery and results of their analyses; open source information; and input received in briefings with experts. All information and assessments so received were carefully reviewed with regard to probative value, authenticity and reliability of the sources. This approach was holistic, using a wide range of information sources and rigid methods of authentication and validation of information received or collected. The IIT assessed the relevance, sufficiency, and credibility of the information gathered, including by corroboration through the use of separate sources. The reliability of documentation and information relating the chain of custody of material and samples was carefully reviewed (including with regard to the time before OPCW investigators had received the samples and material they had not collected themselves), and care was taken to ensure the safety, security and well-being of the persons with whom the investigators interacted.[33]

The final stage in an investigation is reporting. The investigation report is critical for how the subsequent (judicial or political) processes determine whether treaty non-compliance or a criminal act has occurred, and who the perpetrators were that committed the act. It is more than a technical report that recounts the investigation process and its findings. In the context of investigations into

[31] CWC Verification Annex Part IX, paragraph 26, and UN GA document A/44/561 and Addendum 1-3 (4 October 1989), page 30, para 101.c.ii.
[32] See the First Report of the OPCW IIT, OPCW document S/1867/2020, para. 1.7.
[33] OPCW document S/1867/2020, pp. 19-21.

alleged biological weapons use, McLeish and Moon characterised the investigation report as a "boundary document".[34]

The investigation report is directed at specific audiences with particular roles, expectations and needs (e.g., the OPCW Executive Council or the UN Security Council; or an international tribunal or national court). It is to facilitate communications and decision-making processes by these audiences.

One part of the audience needs to understand what investigators did and what they found, and how that confirmed or refuted the allegation. Another part of the audience needs to understand how investigators went about collecting, handling and evaluating the evidence. Are the findings trustworthy and the methods employed valid? Have the findings been interpreted correctly and with what degree of confidence? Where are gaps in the evidence base, and how important are they? Do the conclusions strictly follow from the evidence gathered and analytical tests conducted, and how certain are they?

Typically, international fact-finding mechanisms draw conclusions based on "reasonable grounds".[35] This differs from standards used in certain criminal proceedings, such as "proven beyond reasonable doubt". Consequently, when international investigation bodies transfer evidence to judicial bodies (e.g., national prosecutorial services), their methods and procedures used to gather, manage and interrogate evidence must withstand scrutiny by these bodies.

4. Forensics in investigations of alleged use

Forensic examinations are part and parcel of alleged use investigations. They can involve a wide range of types of evidence (documents, electronic files and data, images, video and voice recordings, physical objects including environmental, biological and clinical samples, etc.). They may aim, amongst others, at identifying individuals that can be linked to certain objects or activities (e.g., fingerprinting of weapons remnants, analysis of voice recordings of communications intercepts), authenticating pieces of evidence (e.g., metadata and analysis of electronic records and devices), or characterising pieces of evidence to demonstrate their function (e.g., reconstruction of weapons from remnants, documents and images, to interpret the relevance of remnants found at an incident site).

In investigations of alleged use of chemical or biological weapons, an essential step is the identification and characterisation of the causative agent(s) and its/their association with the symptoms and clinical effects observed in the victims.

Using progressively more complex methods, laboratory experiments and analyses can also be used to identify the production method used to manufacture an agent; to link an agent found in one location to one found in another; to link an agent to a particular stockpile, or raw material or reagent used in its manufacture; or to test certain hypotheses (for example with regard to the identification of characteristic reaction products of certain chemical agents with materials at an impact site).

Whilst there are certain commonalities between investigating incidents involving chemical warfare agents (typically small molecules), toxins (toxic chemicals of biological origin, often macromolecules), and biological agents (living entities), there are also significant differences. Laboratories often specialise in one or another field of analysis. Even laboratories that can analyse samples related to chemical incidents, biological releases and the use of toxins are in fact not single entities but include distinct, separate branches/units that specialise in particular types of

[34] Caitríona McLeish & Joshua R. Moon (2021): Sitting on the boundary: the role of reports in investigations into alleged biological-weapons use, *The Nonproliferation Review*, DOI: 10.1080/10736700.2020.1872968.
[35] For example, the IIT explained that this meant it would reach "conclusions on the identification of perpetrators on the basis of a sufficient and reliable body of information which, consistent with other information, would allow an ordinarily prudent person to reasonably believe that an individual or entity was involved in the use of chemical weapons".

analysis. The following discussion will therefore address chemical, microbiological and toxin analysis for forensic purposes separately.

4.1. Chemical forensics

Chemical forensics can deploy a wide range of analytical methods to identify and characterise chemicals and mixtures that are associated with the use of hazardous (e.g., poisonous, explosive, inflammable, drugs related) substances. They include a wide range of spectroscopic and spectrometric methods as well as many chromatographic techniques (often coupled with mass spectrometry).[36]

The gold standard used by the OPCW for unambiguous identification involves two independent spectrometric techniques and demonstration of the validity of the identified structure by comparison of the analytical results with those of a validated reference standard. This may require microsynthesis of the chemical provisionally identified).[37] The "work horse" of forensic chemical analyses is mass spectrometry, usually coupled with gas chromatography or high-performance liquid chromatography.

Investigations of allegations of the use of chemical weapons rely on the services of Designated Laboratories of the OPCW. These laboratories must meet a set of rigid administrative, quality assurance and scientific criteria.

These include the implementation of a recognised laboratory quality system such as ISO 17025 certification, participation in at least one official OPCW Proficiency Test (PT) per year, and regularly meeting of certain performance scores in those PTs. These scores differ somewhat depending on whether the designation is for the analysis of environmental samples, or for biomedical analysis.[38]

Environmental samples may include amongst others "neat" agent collected from a reactor or weapon, residues found in reaction or waste containers, or contaminated items such as clothing, hair, soil, rubble or water. The concentrations of chemical agent and / or characteristic degradation products are expected to be fairly high (above 1 microgram / gram), allowing laboratories to perform screening for agents and related products followed by detailed characterisation and confirmatory analyses.

Biomedical samples typically include blood, urine, plasma or tissue. Intact agents are usually no longer fund in such matrices and the search aims at degradation products, reaction products with biomolecules, and metabolites. Concentration levels are expected to be lower than in environmental samples (less than 5 nanogram / gram) and the analysis usually is targeted for the suspected agent.

OPCW Designated Laboratories have demonstrated their proficiency in numerous Proficiency Tests as well as in analyses of authentic verification samples. At the moment, there are 16 laboratories designated by the OPCW for biomedical as well as environmental analysis, plus 9 that are only

[36] Wolstenholme et al. (2021), op. cit.

[37] The conditions for designation of laboratories have been set out in decisions of the First Session of the Conference of the States Parties of the CWC: (C-I/DEC.60, C-I/DEC.61, C-I/DEC.62, and C-I/DEC.65, all dated 22 May 1997). At its Fifth Session (C-V/6, dated 19 May 2000) the Conference mandated the Executive Council to take a decision regarding guidelines on the designation of laboratories for the analysis of authentic samples. The Council took this decision at its Twentieth Session (EC-XX/DEC.3, dated 28 June 2000). Additional guidelines on the designation of laboratories for the analysis of authentic samples were adopted by the Conference at its Twentieth Session (C-20/DEC.4, dated 2 December 2015).

[38] For environmental samples, see for example OPCW document S/1941/2021 (25 March 2021); for biomedical samples see for example OPCW document S/2093/2022 (25 August 222).

designated for environmental sample analysis and another 4 designated only for biomedical samples.[39]

Identifying the causative agent in an incident is the first step in the forensic analysis. If an agent has no natural background (such as Sarin), its detection, identification and characterisation in environmental samples or in the body of victims is by itself strong evidence for the use of a chemical weapon. If an agent has a natural background (such as chlorine), the profile of chemicals related to its dissemination (for example, reaction products with materials at the impact site or in the body of victims) can serve to demonstrate the release of the agent at the incident location.

This type of analysis is well rehearsed by OPCW designated laboratories and certain national laboratories. Maintaining the high standards achieved, and for new laboratories attempting to meet these standards, remains a challenge. Investigations of the alleged use of chemicals that have not been included in proficiency tests and / or target compound databases (for example CNS acting chemicals if disseminated as aerosols[40]), too, can pose difficulties.

Beyond confirming that a chemical weapon has been used and identifying the agent released, a range of additional techniques have been developed (or are being developed) to extract additional information from the samples. These data need to be interpreted in the context of other forensic data such as results of the analysis of written and electronic documents, testimony, technical and design examination of weapons remnants found and other evidence.

In recent years, the OPCW and several national laboratories (including OPCW Designated Labs) have intensified their efforts to further develop forensic analytical approaches that could be deployed for attribution purposes.

In 2016, the OPCW's SAB and VERIFIN organised a workshop to discuss chemical forensics techniques that could be used to this end.[41] Techniques described during this meeting for chemical warfare agent attribution analysis included $^{13}C/^{12}C$ isotopic ratios fingerprinting to identify the origin of abandoned chemical weapons, position specific isotope analysis (NMR) of chemical agents, and impurity profiling and stabile isotope ratio measurements to link batches of sarin, cyanide salts and N mustard (at that time at the proof-of-concept stage). The meeting also looked at chemical forensics methods and approaches used in law enforcement, forensic toxicology, toxin analysis including food safety analysis, the use of chemical forensics in art (authorship attribution, identification of forgeries and copies), and in archaeology.

Participants highlighted the need to enhance forensic awareness and capacity of OPCW inspectors, the potential value of impurity profiling as well as of isotope ration determinations (including for chemicals related to agent production such as solvents or inorganics), the benefit of establishing a data management system including for the collection, curation and mining of data; the potential of developing autonomous systems for sampling and/or on-site detection/analysis; and the benefit from developing biomedical methods for determining exposure to certain toxic industrial chemicals (such as chlorine) used as chemical weapons.

[39] OPCW document S/2089/2022 (15 August 2022) and oral presentations by Daniel Noort (Head, OPCW Laboratory) at EuroBioTox Stakeholder Meeting (Robert Koch Institute. Workshop report, Berlin 2022, in preparation) as well as the 6th UNSGM workshop held by Spiez Laboratory (Spiez Laboratory workshop report, November 2022).
[40] OPCW decision C-26/DEC.10 (2021) clarifies that the use for law enforcement purposes of aerosolized CNS-acting chemicals would not be consistent with law enforcement purposes. A range of potential argents and delivery systems that could be used in this manner have been discussed in the literature, see for example Michael Crowley: "Chemical Control – regulation of incapacitating chemical agent weapons, riot control agents and their means of delivery" Palgrave Macmillan 2015. See also Riches, J., Read, R., Black, R., Cooper, N. and Timperley, C., Analysis of Clothing and Urine from Moscow Theatre Siege Casualties Reveals Carfentanil and Remifentanil Use, *Journal of Analytical Toxicology*, volume 36, 2012, pp.647-656.
[41] OPCW document SAB-24/WP.1 (14 July 2016).

Favourites to investigate synthetic routes of an agent included impurity profiling to detect signatures that are characteristic for a given material stock or batch and that can still be found in the final product mixture, and the analysis of side products and starting materials to find incompletely reacted starting materials and side products that reveal detailed reaction routes and starting materials used ("chemical memory" or source attribution profiles).[42]

Correct sampling and sample preparation are important for successful extraction of information from samples for attribution analysis. While sample preparation methods employed for identification of the causative agent aim to extract the target chemical(s) as efficiently as possible and eliminate any interfering impurities and background chemicals, attribution analysis focuses on precisely such impurities. Also, some extraction solvents may contain the same impurities as the ones studied.[43] Vanninen et al. describe in some detail the different sample preparation methods that have been published in the literature for attribution analysis for chemical warfare agents. They discussed different matrices (dust, food, painted wallboard, glass, vinyl tiles, concrete, carpet) as well as the statistical methods used to analyse the data.[44] They concluded that:

> "Currently used sampling and sample preparation methods mostly focus on the identification of an alleged chemical like sarin, mostly ignoring the impurities in the sample. Since attribution analysis is entering the OPCW's mandate for investigations, the feasibility of the sampling and sample preparation procedures will need to be evaluated and procedures modified and developed accordingly."[45]

As for instrumental analysis methods and protocols, attribution analysis can make use of available techniques, and combine data measured by different such techniques as necessary to improve source matching. Chemometrics tools for data analysis and interpretation are increasingly important. So are benchmarking datasets, and there is a need to develop guidelines for data treatment and processing to ensure reproducible results.[46]

To study further the requirements of chemical case investigations, the OPCW established an SAB temporary working group (TWG) on investigative sciences. Its report was published in December 2019.[47] It included a wide range of recommendations dealing with forensic methods and capabilities, data collection and management, detection and analysis methods, provenancing and more general proposals to enhance the investigation process.

The SAB highlighted the utility of examining extrinsic chemical signatures such as impurities or additives, and of intrinsic signatures such as stable isotope ratios. These methods can be used to match two or more samples with a suspected common origin or to provenance agent samples originating from a common source.

Matching usually requires samples that are comparable in concentration and matrix. This makes it difficult to link environmental samples with neat agents in stockpile, or to detect markers in trace amounts. There are also knowledge gaps about common variations in relevant chemical profiles,

[42] Vanninen, P., Hakulinen, H. I., Heikkinen, H. A., Kiljunen, H., Silva, O. S., Aalto, S., & Kauppila, T. J. (2020). Chemical Forensics. In M. Martellini, & R. Trapp (Eds.), *21st Century Prometheus: Managing CBRN Safety and Security Affected by Cutting-Edge Technologies* (1 ed., pp. 255-286). Springer.
[43] Vanninen et al. (2020), op. cit., p. 273, referencing Fraga, C.G., L.H. Sego, J.C. Hoggard, G.A.P. Acosta, E.A. Viglino, J.H. Wahl, and R.E. Synovec. "Preliminary effects of real-world factors on the recovery and exploitation of forensic impurity profiles of a nerve-agent simulant from office media". *Journal of Chromatography*. A 1270: 269–282 (2012).
[44] Vanninen et al. op. cit., pp. 273-79.
[45] Vanninen et al. op. cit., p. 279.
[46] Vanninen et al., op. cit, p. 281.
[47] OPCW document SAB/REP/1/19 (2019).

and reference data are often not available for provenancing a sample from a single event with regard to production method, storage/handling conditions or other life cycle signatures.[48]

The SAB recommended, amongst others, that a new TWG should be established on investigating the provenance of samples of chemicals relevant to the CWC. Also, the OPCW should develop a profiling database for raw instrument data of samples of chemical threat agents of known provenance, including but not limited to additives, synthetic impurities and degradation products. The Secretariat and Designated Laboratories should engage and where possible participate in projects of the Chemical Forensics International Technical Working Group (CFITWG),[49] which develops peer reviewed chemical profiling approaches and exchanges information on provenance determination of chemical warfare agents and related compounds. Finally, scientific results of work on chemical profiling should be published in peer reviewed literature to demonstrate the validity and robustness of methods and enable data comparison.

In summary, the forensic capacity available to the international community to investigate chemical incidents has increased significantly over the past ten years. Procedures, methods, standards and criteria to confirm a use of a toxic chemical as a weapon are fit for purpose, mature and well exercised. The OPCW's network of Designated Laboratories is a valuable, top-of-the-range resource for international investigations of chemical weapons use allegations.

The new ChemTech Centre of the OPCW will provide a welcome expanded platform for collaborations between OPCW Member States and to render technical assistance in chemical analysis to countries that need such support.

When it comes to provenancing, progress is being made but there remain significant challenges before the full potential of these methods can be exploited. Methods development and validation, the development and expansion of curated databases and repositories, enhanced data management tools, and agreed assessment criteria are still being developed. As methods and reference standards and materials mature, operating procedures used by different laboratories will need to be harmonised (moving towards recommended and ultimately standard operating procedures) to make results from different laboratories comparable. Systematic high-quality research and international collaborations are essential to move forward.

4.2. Microbial forensics

Microbial forensics, too, has made significant progress in recent decades. In part, this is the result of the rapid advances in the life sciences and the impact of convergence in associated scientific and engineering disciplines. Enabling technologies that have contributed to this progress include automation and miniaturisation of labour-intensive processes, a hugely increased computational capacity and ever-expanding databases, bioinformatics pipelines and tools, and new tools in genome sequencing, writing and editing.

In addition to the advances in the life sciences, progress in microbial forensics was the result of specific investigations that required the development and validation of new analytical methods as well as microbial databases and strain repositories.

A key example was the FBI investigation of the Anthrax letter attacks in the United Sates in 2001. It lasted from 2001 to February 2010 and involved extensive physical and chemical analysis.[50] It

[48] OPCW document SAB/REP/1/19, pp. 58-61.
[49] See https://www.state.gov/chemical-forensics-international-technical-working-group/#:~:text=The%20U.S.%20Department%20of%20State,%2C%20and%20export%2Dcontrol%20organizations.
[50] K. L. Warmbrod, M. Montague and N. D. Connell, "Microbial Forensics: Detection and Characterization in the Twenty-first Century", in M. Martellini and R. Trapp (eds.), *21st Century Prometheus*, Springer 2020, pp. 358-9.

consumed some 600,000 investigation work hours, involved 17 Special Agents supported by 10 US Postal Inspectors, and was assisted by 29 governmental, industry and university laboratories.[51]

Although certain new methods such as "next generation" DNA sequencing were not deployed, other new laboratory methods (such as highly specific molecular-genetic assays) were developed. The investigation involved initial strain identification, and the characterisation of unique distinguishing features to compare strains of different origin (for which a dedicated repository of Ames strain *B. anthracis* was created). Variant identification was based on colony morphology and the identification of genetic mutations associated with these morphological variants. Analytical methods such as scanning and transmission electron microscopy, energy-dispersed X-ray analysis, carbon dating, inductively coupled plasma-optical emission and mass spectrometry were used to determine chemical and elemental profiles of the spore powders.[52]

Based on this intensive and lengthy investigation, the FBI was confident it could link the attack strain to a single flask container and its content. Despite these efforts, however, it was not possible to reach a definite conclusion about the origin of the attack strain based on the scientific evidence alone.[53] A subsequent study also identified certain shortcomings in the standardisation of the testing processes used, and pointed to existing gaps in the understanding of how exactly bacteria mutate in nature versus the laboratory.[54]

In 2014, the National Research Council of the US National Academies in cooperation with the Croatian Academy of Sciences and Arts, the U.K. Royal Society and the International Union of Microbiological Societies reviewed in depth the evolving field of microbial forensics. At an international conference, they highlighted a wide range of needs in the field of microbial forensics.[55] A far broader and systematic knowledge base about endemism and background is needed. High-confidence methods are needed to distinguish among natural, accidental, and deliberate outbreaks of infectious diseases. There are gaps in methods validation, and a more systematic and comprehensive establishment of reference collections and databases for pathogens and other microorganisms will be critical. Political and institutional barriers exist in relation to the sharing of data and in general, there is a need to ensure that these efforts would evolve truly internationally.

The conference also identified ongoing efforts that are important to further enhance microbial forensics, including research into the mechanisms of pathogenicity such as virulence factors and host immune response, the utilization of metagenomics and other "omics" for forensic purposes, improved physical science applications and bioinformatics / statistical methods including algorithms for very large or complex data sets, and improvements in molecular diagnostics and disease surveillance and monitoring.[56]

Short-term priorities included the improvement of existing assays and techniques (faster, cheaper, standardised, more widely accessible), the compilation of existing protocols including their validation, and expanded training.[57] A recent review also drew attention to genetic sequencing techniques (with emphasis on next generation or "deep" DNA sequencing, and amplicon sequencing), metagenomic analysis of microbial communities associated with forensic samples, and the use of microbiomes as unique markers to identify individuals (a sort of microbial

[51] National Academy of Sciences, National Research Council (NRC): *Review of the scientific approaches used during the FBI's investigation of the 2001 Anthrax letters*, Washington DC (2011).
[52] NRC (2011), op. cit., pp. 4-10.
[53] NRC (2011), op. cit., Summary of Committee Findings, p. 4.
[54] US Government Accounting Office (GAO), *Anthrax – Agency approaches to validation and statistical analyses could be improves*, GAO-15-80 (2014), p. 52
[55] National Academy of Sciences, National Research Council (NRC), *Science needs for microbial forensics: Developing initial international research priorities. Washington*, DC (2014), pp.4-5.
[56] Ibid.
[57] Ibid.

fingerprint). It also pointed to challenges associated with contamination, endemism and background noise, and identified the need for curated repositories and databases.[58]

But how do these evolving scientific capabilities affect the international capacity to investigate alleged BW uses?

The UNSGM is the only international mechanism dedicated specifically to investigate alleged biological weapons uses.

30 Member States have nominated a total of 83 laboratories for the analysis of microbial agents to the UNSGM.[59] Different from the CWC system, there is no formal designation procedure, and neither are official proficiency tests being conducted to evaluate and demonstrate the competence and procedural compliance of these laboratories. Since the UNSGM investigation in Syria in 2013, the UN and a number of countries have been working towards setting up a network of trusted UNSGM laboratories. They have conducted practical quality assurance exercises, developed guidelines and criteria, and identified critical capacity gaps. These activities are coordinated by the United Nations Office of Disarmament Affairs (UNODA) and through a Group of Friends of the UNSGM. Spiez Laboratory has been providing a platform for discussions, sharing results of exercises and other work conducted, and planning.

Between 2015 and 2022, seven UNSGM workshops have been hosted by Spiez Laboratory. In addition, workshops were held in Geneva (2016) sponsored by the United States, Stockholm (2015) and Umeå (2016) hosted by the Swedish Defence Research Establishment (FOI), and Berlin (2020) organised by the Robert Koch Institute with support from the United States.
These discussions have clarified the requirements for forensic microbiological analysis in a UNSGM context:[60]

- There are three distinct stages of such investigations: agent identification, agent characterisation (unexpected or unusual features of the agent, epidemiological anomalies), and examination of evidence to support the identification of possible sources and perpetrators of an agent release.
- Scientific competence, strong quality assurance systems, high biosafety standards and forensic as well as procedural compliance including an unbroken chain of custody are essential for laboratories to support a UNSGM investigation.
- For unambiguous identification, laboratories will have to employ multiple orthogonal analytical techniques using validated methods, and standard or recommended operating procedures and agreed acceptance criteria for analytical results are needed.
- It is important to ensure access to validated reference standards and curated databases.
- Although there are many competent laboratories in the field, the target agents as well as sample types in an investigation may differ from what laboratories in the public health or animal/plant health domains are accustomed to.
- There is a need for guidance on appropriate sample collection, packaging and shipment, and for close interaction between field investigators and the laboratories that conduct the analysis.
- Laboratory expertise needs to be embedded in the field investigation teams to ensure that samples are selected, collected and managed correctly.

[58] Warmbrod et al. (2020), pp. 360-5.
[59] The UNSGM is a 'Member State mechanism' that depends on the resources nominated to the SG by UN Member States. UNODA acts as custodian of the mechanism and has a limited in-house capacity to manage the administrative issues related to the mechanism, but no operational resources itself. At the end of 2022, Member States have nominated 530 qualified experts as potential investigators, 59 expert consultants that can advise the SG on scientific, operational, legal and other issues, and 83 laboratories from 30 countries. In addition, the UNSGM can rely on support from partners such as the OPCW, WHO, WOAH and others.
[60] Spiez Laboratory "UNSGM Designated Laboratories Workshop Report 14 – 16 September 2022"

- The reporting of analytical results must withstand both technical and political/legal scrutiny: it must demonstrate an unbroken chain of custody as well as the quality assurance and validation processes applied, and describe findings as specifically as the capabilities of the performed analyses and tests allow.

To better define these requirements, build capacity and facilitate collaborations among laboratories, several countries have carried out projects involving interlaboratory exercises. Germany has been implementing its RefBio Project since 2017 (extended in 2022 and scheduled to continue until 2024). This project organises external quality assurance exercises (EQAEs) in three areas: bacteria, viruses, and toxins. By 2022, 38 laboratories from 21 countries have participated in these exercises. Laboratories are given a series of tasks with increasing levels of complexity. For example, in the most recent bacteriological test, participants were asked to identify the samples testing positive or negative for Brucella, the Brucella species, and the agent at bacterial strain level. They were asked also to perform a molecular characterisation (MVLA and MLST profile, antibiotic resistance, virulence genes). Whilst most laboratories succeeded with correctly identifying the agent positive and negative samples, Species and strain identification was more challenging. Screening capabilities for antibiotic resistance and virulence genes were available in many laboratories, but the findings often would not have allowed conclusions about antibiotic resistance. Standard molecular assays were sometimes hampered by difficult matrices.[61]

Other countries, too, have organised lab exercises. China's State Key Laboratory for Infectious Diseases organised an exercise to identify and characterise an unknown "disease X" and establish its animal origin. The exercise involved pathogen identification as well as identification of the animal carrier, and analysing different clinical, animal and vector samples. Participation was coordinated through UNODA as custodian of the UNSGM.

Denmark, Sweden and Germany conducted a series of dry lab (bioinformatics) exercises, with financial support from the United States. Laboratories were requested to identify viral reads, characterise the genome (species and strain identification), and compare genomes to find clues of genetic engineering and biological weapons use.

The RefBio project has been working on a generic reporting format for investigations of biological (and perhaps toxin) weapons investigations.[62] This UNSGM reporting template would have to be internationally court-proof and "politically correct". Several national agencies and laboratories as well as UNODA, WOAH and WHO have contributed to this work. Different from OPCW's approach, the report is not meant to contain actual raw analytical data but to summarise the findings of the analyses conducted. However, administrative and analytical details would need to be made available if requested, and the entire administrative and analytical process needs to be documented in every detail to be able to meet any legal challenges.

A set of guidance documents on sample planning and collection, sample management, packaging, storage and transfer has also been developed, led by Canada and supported by a number of other countries.[63] Experience from the COVID-19 pandemic was valuable in developing these guidelines.

[61] Ibid., pp. 11-12.
[62] Ibid., pp. 17-19.
[63] Ibid., pp. 22-26.

All the different elements of a biological investigation that have been developed and revised in recent years are being tested in field exercises.[64]

In summary, significant progress has been made in enhancing the scientific capacity to investigate alleged biological weapons uses. There remain certain gaps, amongst others with regard to the knowledge base, methods validation, repositories, curated databases and certified reference materials. Also, microbial forensics is not itself a “silver bullet” and its results need to be interpreted in the context of all other information gathered. Despite these challenges, an investigation would stand a reasonable chance to distinguish between natural and manmade biological events and to gather data that might assist in the identification of those responsible.

4.3. Toxin analysis

Toxins are covered by the CWC as well as the BWC, and their use as a weapon could become subject to an alleged use investigation by the OPCW as well as the UNSGM. They are toxic chemicals of biological origin, and two of them (Ricin and Saxitoxin) are listed in Schedule 1 of the CWC. In theory, given that toxins are doubly covered under the law, tools to investigated incidents involving toxins should be readily available. In practice, the situation is more complicated.

Toxins exhibit extreme toxicity (poisonous in the pg/ml range). Hence, the concentration levels for detection and forensic analysis are significantly lower than in traditional chemical analysis. Structure and molecular weight of toxins vary widely, ranging from relatively simple molecules such as Saxitoxin to complex protein structures.[65]

To give an example, the natural sequence diversity of botulinum neurotoxins includes 8 serotypes and over 40 subtypes, and there are 6 different Clostridium species that produce BoNT toxins.[66] This results in more than 40 different BoNT toxins. At the same time, low molecular weight (LMW) and high molecular weight (HMW) toxins require different analytical methods, tools reference materials, technical instrumentation, and expertise.[67]

Although they are toxic chemicals, toxins are not as yet included in the OPCW’s laboratory designation process. Six confidence building exercises on toxin analysis have been conducted so far, focusing on the Schedule 1 toxins Ricin and Saxitoxin.[68]

In the most recent OPCW exercise, participating laboratories were encouraged to attempt toxin quantification, match samples by their toxin profile or impurities present, and comment on the sophistication of the toxin preparation (in particular for protein toxins). The exercise showed increased proficiency among the participating laboratories. At the same time, whilst toxin identification *per se* was managed reasonably well by most participants, the exercise exposed certain shortfalls in tests relevant to possible attribution.

[64] The latest such exercise was the Capstone Exercise hosted by the Robert Koch Institute Berlin, in cooperation with UNODA. See https://www.un.org/disarmament/zh/update/capstone-exercise-for-the-united-nations-secretary-generals-mechanism-for-the-investigation-of-alleged-use-of-chemical-and-biological-weapons-unsgm/ for details.
[65] For a discussion of relevant types of toxins see, for example, Robert Koch Institute, Workshop Report “Biotoxins – relevant molecules under UNSGM and OPCW activities” Berlin 2020. The workshop discussed Saxitoxin and other PSP toxins, ricin, botulinum neurotoxins and staphylococcus enterotoxins as relevant examples.
[66] Ibid., p. 10.
[67] Ibid., p. 19
[68] Robert Koch Institute: Workshop report: *Stakeholder Meeting Report EuroBioTox – European Programme for the Establishment of Validated Procedures for the Detection and Identification of Biological Toxins (Brussels 7 September 2022)*, Berlin (to be published in 2023).

Whether and how quickly the OPCW will move from confidence building exercises to conducting Proficiency Tests would depend on interest and willingness of the laboratories, and it would require updating quality assurance documentation as well as ISO certification of the OPCW Laboratory. At least initially, the focus would likely remain on Saxitoxin and Ricin as target toxins.[69]

Other toxins have not yet been included in this scheme, partly as a reflection of OPCW's traditional focus on scheduled chemicals, partly also as a result of the huge variety of toxins that could theoretically be of interest. The OPCW's SAB reflected on the differences between LMW toxins (such as Saxitoxin) and HMW toxins (such as Ricin). Whilst LMW toxins are amenable to the classical analytical techniques used by OPCW designated laboratories, HMW toxins require methods more akin to biological analysis - functionality tests such as ELISA, antibody binding, DNA sequencing). Forensic analysis will require the demonstration of the chemical composition, structure and biological activity.[70]

A number of issues relevant to the further development of forensic capabilities for toxin analysis have been identified:[71]

- MS based analytical methods need to be combined with immunological capabilities
- The variety of sample types and scenarios requires methods to assess both active and denatured toxins, to inform relationships with natural backgrounds, and bioinformatic methods to leverage complex datasets
- The toxins must be quantified, and the required detection limits in specific scenarios need to be agreed
- For proteins, multiple orthogonal approaches need to be employed, which calls for standardised acceptance criteria
- Sample size or type may limit the types of analyses that can be performed
- Reference materials and specific reagents (e.g., antibodies) are needed for method validation and to interpret conclusions
- There is a need for standardisation of methods, libraries, bioinformatic predictions, biomarkers, performance and acceptance criteria, quality control materials and validation procedures, and operating procedures for common methods
- Guidelines are needed for spectral interpretation and method limitations
- Laboratories should participate in Proficiency Tests and real-life scenarios
- Quality management systems with documented regular training need to be established
- Accurate science communication skills are important for communications by laboratories to non-experts.

Different from chemical agent analysis, only a few laboratories are skilled in the detection, identification, and characterization of both HMW and LMW toxins.

The majority of expert laboratories focus on individual toxins as relevant to security/verification, public health, and/or food safety purposes.[72] This creates challenges with regard to the development of a coherent and comprehensive international as well as national approach to developing a forensic capacity for toxin analysis.

The SAB also recommended that the OPCW should set up a TWG to advise on required capabilities for the analysis of relevant biological toxins.[73] This group held five meetings by November 2022, and addressed a series of questions related to underlying requirements for toxin analysis, the most

[69] Robert Koch Institute. *Workshop report: EuroBioTox Stakeholder Meeting*, Berlin 2022 (publication in preparation).
[70] SAB/REP/1/19. p. 48.
[71] Robert Koch Institute. *Workshop report: Biotoxins - relevant molecules under UNSGM and OPCW activities*, Berlin 2020, pp. 16-17
[72] Ibid., p. 19
[73] SAB/REP/1/19, recommendation 30, p. 19.

likely range and nature of toxins and other biomolecules that might have to be analysed, analytical standards and requirements of other international and national investigative authorities, opportunities for collaborations with other networks to minimise duplication, promote consistent practices and develop a comprehensive map of existing capabilities, and institutional and legal measures that would facilitate collaborations between the OPCW and other relevant organisations.[74]

A final report is expected early in 2023. Whilst a lot of material of interest has been published in the five interim reports of this TWG, it would be premature to comment in detail on its findings until its final report has been published.

What has emerged, however, is that a number of additional toxins are of interest for investigations of alleged uses based on their potential for use as a chemical weapon.

The OPCW designated laboratories network has already developed a high capacity for analysing Saxitoxin and Ricin. In all likelihood, however, the OPCW would have to depend on external expert laboratories for the analysis of a broader range of toxins which would require the use of specific reagents and methods outside the current scope of most OPCW designated laboratories.[75]
Such a use of external laboratories would pose questions with regard to their ability to comply with requirements of national or international investigations, in particular with regard to the protection and documentation of an unbroken chain of custody and the reporting of analytical results in a manner that meets forensic standards.

In the context of the UNSGM, work is under way to consolidate and further enhance the existing capabilities in toxin analysis and to network with all relevant partners. Whilst the OPCW is likely to focus on Ricin and Saxitoxin, other laboratories such as those involved in the German RefBio project or the EuroBioTox project could focus on other types of toxins. There remain significant gaps as well as institutional challenges, however, including with regard to political awareness for the need to invest in this field.

5. What next?

The procedural and legal framework for investigations of allegations of the use of chemical, biological or toxin weapons have evolved in recent years, influenced by reactions to the use of chemical weapons in the Middle East (in particular in Syria) as well as the use of nerve agents from past military programmes in assassination attempts in several countries. “Attribution” was not a term used in the context of investigations in the past – today it is.

Attribution requires the gathering and interrogation of evidence and contextual information using forensic techniques and approaches. The science and technology in this field is evolving fast, and an increasing range of methods can support provenancing of an agent retrieved at an incident site.

But there remain significant gaps in the knowledge base as well as with regard to methods development and validation, access to certified standards and curated repositories and databases, and harmonised (and eventually standardised) operating procedures and protocols.

This does not mean that investigations that aim at attributing responsibility for the use of chemical, biological or toxin weapons are not possible to the standards required in court. Today’s science and investigative tools can and are being used to this end: in fact, the work of the OPCW’s IIT, the JIM, the IIIM, and national investigations have shown that attribution is possible. Investigations will

[74] OPCW document SAB-36/WP.2 (17 November 2022).
[75] See also Robert Koch Institute. *Workshop report: EuroBioTox Stakeholder Meeting*, Berlin 2022 (publication in preparation).

however often involve an element of research rather than simply employing a suit of fully developed and validated methods. They may also require laboratory experiments to test hypotheses and fill knowledge gaps, or to develop and validate reference materials or create repositories. These steps will take time. Expectations that such investigations may deliver conclusive results in short periods of time - the CWC Verification Annex for example prescribes a submission time for the final investigation report of 30 days - are unrealistic. The work of the IIT has shown that for complex scenarios such as the 2018 attack in Douma, investigation times need to be counted in months if not years.

The further development of forensic capabilities in the investigation of alleged CBW uses will require intensive scientific collaborations on a global scale. The OPCW's ChemTech Centre is expected to create new opportunities for international collaborations and confidence building in this field. Also, additional laboratories are likely required to join the effort to create a broader and trusted international laboratory network for provenancing and attribution analysis.

It seems most likely that the emerging capabilities will be tested first in national courts rather than international tribunals. But it will be important to prepare for possible international criminal prosecution efforts in the future, and build up scientific capacity that is broadly trusted by States from all regions when this happens. Managing these efforts will pose institutional challenges and call for adequate resources.

It needs to be seen how far the OPCW is prepared to venture into as yet uncharted territory: investigations into allegations involving unscheduled chemicals, or toxins other than Ricin and Saxitoxin, or other types of biomolecules such as bioregulators, or synthetic agents acting on the CNS such as fentanyl derivatives. Whilst all these and other toxic chemicals fall within the scope of the CWC, there is a limit to what the OPCW and its designated laboratories can manage to add to their existing portfolios without overstretching existing capacity or compromising quality. How external expert laboratories can be involved needs to be further clarified. A closer cooperation and division of labour between the OPCW and the UNSGM in the toxin area, for example, would be desirable.

In the biological sector, the efforts to strengthen the UNSGM are expected to make further progress despite the lack of an institutional framework comparable to the OPCW. What is emerging is a network of trusted laboratories able to withstand the legal, political, procedural and scientific scrutiny to be expected in a UNSGM case. The main challenges are political and institutional: continuity in the efforts to strengthen the operational capacity of the UNSGM, political support and sufficient resources to develop a competent and trusted global laboratory infrastructure, and a political culture that is capable of dealing with allegations in a serious and responsible manner.

> *Finally, it would be desirable to more clearly define the interface between the technical capacity being built up in the context of arms control and disarmament treaties and mechanisms on the one hand, and human rights and criminal law on the other.*

There remains a certain unease about using arms control mechanisms to address issues that are in essence issues of criminal responsibility. This is not to say that this cannot be done, but the implications of such an approach need to be fully recognised. It is clear that impunity for the use of chemical and biological weapons cannot be tolerated if the norms against these outlawed methods of warfare are to be protected. Internationally, the scientific competence to investigate use allegations rests with the organisations and mechanisms entrusted with enforcing these arms control norms. How they interface with criminal law mechanisms and organisations ought to be further delineated.

The CBW network for the comprehensive strengthening of norms against chemical and biological weapons (CBWNet)

The research project CBWNet is carried out jointly by the Berlin office of the Institute for Peace Research and Security Policy at the University of Hamburg (IFSH), the Chair for Public Law and International Law at the University of Gießen, the Peace Research Institute Frankfurt (PRIF) and the Carl Friedrich Weizsäcker-Centre for Science and Peace Research (ZNF) at the University of Hamburg. The joint project aims to identify options to comprehensively strengthen the norms against chemical and biological weapons (CBW).

These norms have increasingly been challenged in recent years, *inter alia* by the repeated use of chemical weapons in Syria. The project scrutinizes the forms and consequences of norm contestations within the CBW prohibition regimes from an interdisciplinary perspective. This includes a comprehensive analysis of the normative order of the regimes as well as an investigation of the possible consequences which technological developments, international security dynamics or terrorist threats might yield for the CBW prohibition regimes. Wherever research results point to challenges for or a weakening of CBW norms, the project partners will develop options and proposals to uphold or strengthen these norms and to enhance their resilience.

The joint research project is being funded by the Federal Ministry of Education and Research for four years (April 2022 until March 2026).

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