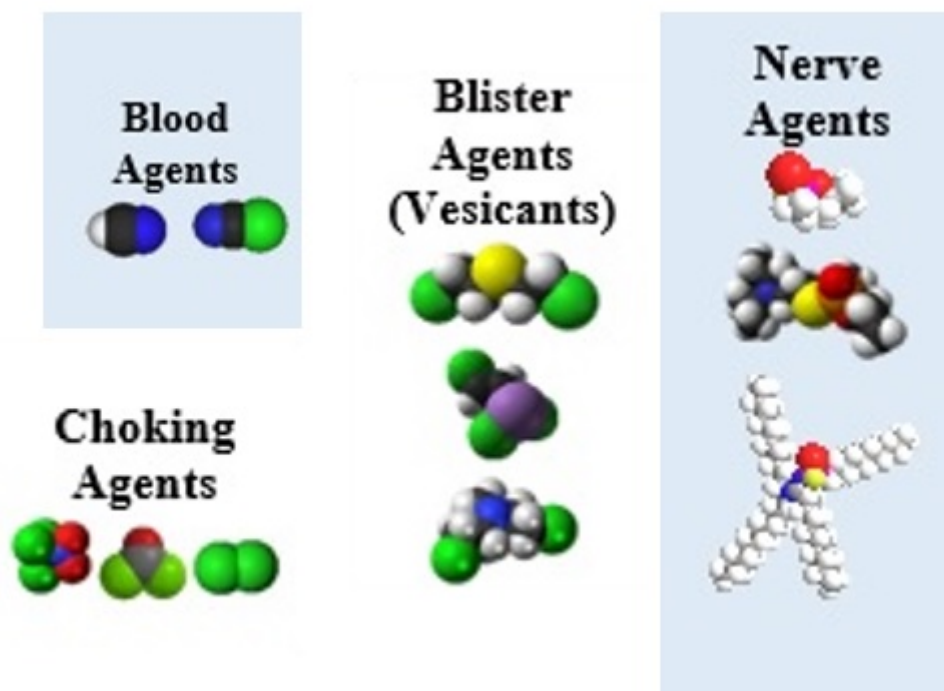




CHEMICAL WEAPONS IN THE ASIA-PACIFIC: HISTORY, SCIENCE, AND FUTURE PROSPECT



Recommended Citation

Jonathan Forman and Alexander Kelle, "CHEMICAL WEAPONS IN THE ASIA-PACIFIC: HISTORY, SCIENCE, AND FUTURE PROSPECT", NAPSNet Special Reports, March 17, 2022, <https://nautilus.org/napsnet/napsnet-special-reports/chemical-weapons-in-the-asia-pacific-history-science-and-future-prospect/>

JONATHAN FORMAN AND ALEXANDER KELLE

MARCH 18 2022

I. INTRODUCTION

In this essay, Jonathan Forman and Alexander Kelle visit some of the darkest episodes of past wars

to remind us of the experimentation and use of chemical weapons in the Asia-Pacific region and the problem presented by modern chemical industry and innovation for maintaining the modern non-use norm for chemical weapons.

Jonathan Forman served as Science Policy Adviser at the Organization for the Prohibition of Chemical Weapons (OPCW) from March 2013 to January 2020 and non-resident Scholar at James Martin Center for Nonproliferation Studies since 2019. Alexander Kelle is a Senior Researcher at the Berlin Office of the Institute for Peace Research and Security Policy (IFSH) at the University of Hamburg, Germany. He served as a Senior Policy Officer at the OPCW from February 2013 to December 2019.

This paper was presented to Weapons of Mass Destruction (WMD) in the Asia-Pacific Workshop, December 1-4, 2020, Asia Pacific Leadership Network for Nuclear Non-proliferation and Disarmament and published by APLN [here](#). It is part of an upcoming edited volume WMD in Asia Pacific: Trends and Prospects.

Acknowledgement: The workshop was funded by the Asia Research Fund (Seoul).

The views expressed herein are those of the authors and do not necessarily reflect those of OPCW. Alexander Kelle's contribution to this report has benefitted from a grant of the German Foundation for Peace Research to the IFSH, grant number SP03/05/2020. This support is herewith gratefully acknowledged.

The views expressed in this report do not necessarily reflect the official policy or position of the Nautilus Institute. Readers should note that Nautilus seeks a diversity of views and opinions on significant topics in order to identify common ground.

This report is published under a 4.0 International Creative Commons License the terms of which are found [here](#).

Banner image: chemical weapon molecules, Table 1 this special report.

II. NAPSNET SPECIAL REPORT BY JONATHAN FORMAN AND ALEXANDER KELLE

CHEMICAL WEAPONS IN THE ASIA-PACIFIC: HISTORY, SCIENCE, AND FUTURE PROSPECT

MARCH 18 2022

Introduction

From ancient times through 20th century wars, chemicals as weapons have a long history, with development and use of chemical weapons by both state and non-state actors. Since 1997, with the entry-into-force of the Chemical Weapons Convention (CWC), the nations of world have agreed to eliminate chemical weapons and allow the verified destruction of stockpiles declared by possessor States. The Asia-Pacific region^[1] includes three possessor states: Russia, the ROK, and the United States, as well as chemical munitions abandoned by other states in past wars, most notably by Japanese forces while retreating from China at the end of the Second World War. The DPRK, however, remains outside the CWC and is widely believed to maintain a chemical weapon stockpile. Alongside the efforts of states at chemical demilitarization, chemicals have continued to be used in harmful ways by terrorist groups and in targeted attacks that are linked to several Asia-Pacific

States.

Science and technology have provided us with advancements well beyond the state-of-the-art that produced the chemical arsenals of 20th century militaries and is often called out as a challenge to maintaining the norms of the CWC. Yet, we also see scientific research with potential to strengthen capabilities to control, prevent, and respond to chemical threats; and, recent examples of chemical attacks have not showcased the adoption of advanced technologies, as much as they have demonstrated unexpected approaches for deployment of previously known chemical weapons. The misuse of chemistry to harm people, the verification of destruction of chemical arsenals, and the effective mitigation and response to chemical threats requires a sound understanding of the underlying scientific basis of chemical weapons and associated technologies. These activities also require transdisciplinary technical capabilities. At the same time, disarmament and non-proliferation instruments like the CWC have set clear boundaries on what defines a chemical weapon and what chemical weapon related scientific research and development is allowed. This report will discuss the history of chemical weapons use and programs, progress in chemical disarmament, and aspects of the science and technology that informs these efforts. The chapter concludes with an assessment of the current state of affairs and provides an outlook on the future prospects for chemical weapons use and mitigation in the Asia-Pacific.

Chemicals in War and the Prohibition of Chemical Weapons

Chemicals have seen use in war throughout history from ancient to modern times,^{[2],[3]} with weaponized chemicals encompassing a broad range of substances and harmful effects. Familiar and historical examples include incendiary mixtures such as “Greek fire”² and napalm,^{[4],[5]} pyrophoric materials such as white phosphorus (commonly used for illumination and generation of smoke),⁵ poisons for coating the tips of weapons,^{2,[6]} gun powder (invented in 10th century China^[7]) and explosives,^[8] toxic and asphyxiating gases (such as chlorine),^{3,6,[9]} blistering agents (such as sulfur mustard),^[10] nerve agents (such as sarin),^[11] and herbicides (the most infamous being agent orange which was used in conflicts in Malaya and Vietnam^[12]).

Asia-Pacific states began contributing to international efforts to restrict the use of chemical weapons in the 19th century. In 1874, an initiative was put forward by Czar Alexander II of Russia, which led to the Brussels Declaration Concerning Laws and Customs of War. The declaration included a ban on the use of poison and poisoned weapons within its prohibitions; however, it never entered into force.^[13] The discussions that began in 1874 did lead to agreements on banning poisons and poisoned weapons, as well as the use of projectiles that diffuse asphyxiating or deleterious gases through provisions found within the Hague Conventions of 1899 and 1907.^[14] Before the first-world war, Asia-Pacific states party to these Conventions included China, Fiji, Japan, Korea, Russia, and the United States, additionally territories and colonies in Asia-Pacific would have been obligated to these Conventions through colonial powers that were party to the Hague Conventions (which included the major world powers of the day).^[15]

With the First World War giving rise to the use of toxic chemicals on a scale never before seen in the history of war,^{2,6,9} the Hague Convention bans on poisons and gases were short lived. This war saw chemicals deployed on industrial scales, as well as research and development that led to the weaponization of new types of chemicals posing both breathing and skin contact hazards. The first recorded use of chemicals in World War I was the firing of tear gas by French forces in 1914,^[16] and by the end of the conflict numerous other chemical substances, many with far greater lethality and hazardous properties, had been tested and/or deployed in battle.^{3,6,9,16}

The use of chemicals in World War I gave rise to the Geneva Protocol of 1925. This agreement banned asphyxiating, poisonous or other gases and analogous liquids, materials, or devices in war,

and also bacteriological methods of warfare.^[17] The Protocol allowed states to ratify with reservations allowing the use of the banned weapons against states not party and in retaliation to an attack using banned weapons. By the mid-1930's, States Parties from Asia-Pacific included Australia, Canada, and Russia (as the Soviet Union). Chemical weapons were still used in the region in World War II by Japanese forces in China,^[18] and tear gas was deployed against enemy combatants by the United States in the Vietnam war.^[19] Both Japan and the United States had signed the Geneva Protocol in 1925, but these states did not ratify/accede to the protocol until 1970 (Japan) and 1975 (USA) respectively.¹⁷ China became a State Party to the Geneva Protocol in 1952 and Vietnam in 1970. With the exception of Kiribati, Micronesia, Marshall Islands, Nauru, Palau, Samoa, Singapore, Tuvalu, and Vanuatu, which are not party to the protocol, the other States in the region joined after World War II.¹⁷

During the Cold War, the United States and the Soviet Union produced large stockpiles of chemical weapons, including highly toxic organophosphorus nerve agents,¹¹ and programs to develop new types of chemical weapons continued in a number of states.¹¹ Discussions to ban both chemical and biological weapons began again at the Disarmament Conference in Geneva in 1968. The Biological and Toxins Weapons Convention opened for signature in 1972,^[20] but the negotiations that eventually led to the Chemical Weapons Convention (CWC),^[21] which comprehensively prohibits chemical weapons, continued. It was not until 1993, that the CWC opened for signature, with its entry-into-force in 1997.

The CWC opened a new era in prohibiting chemical weapons. Unlike the multilateral treaties that preceded it, with exception of the Biological and Toxin Weapons Convention (BTWC), it was a complete ban on an entire class of weapons of mass destruction (WMD). In contrast to the BTWC, however, it created an implementing organization, the Organisation for the Prohibition of Chemical Weapons (OPCW),^[22] and included a verification regime. Today there are 193 States Parties to the CWC.^[23] Only four world states remain outside this Convention; only one of these states is in Asia-Pacific, the DPRK. The successes of the CWC were recognized by the award of the Nobel Peace Prize to OPCW in 2013 for its extensive efforts to eliminate chemical weapons.^[24]

The CWC prohibits the development, production, acquisition, stockpiling, retention, transfer, or use of chemical weapons. State Parties must destroy chemical weapon stockpiles and chemical weapon production facilities in their possession. As of March 2022, 71,614 (99%) of the 72,304 metric tonnes of chemical warfare agents declared by States Parties have been destroyed under international verification.^[25] Of the ninety-seven declared chemical weapons production facilities, seventy-four have been destroyed and twenty-three converted to other (allowed) uses, all under international verification.²⁵ States Parties must also participate in a verification regime that allows international inspectors access to their chemical facilities, including commercial production sites.^[26] These states must also implement national laws that include provisions for the regulation of production and transfer of certain "Scheduled" chemicals.^[27] Additionally, the CWC contains Articles for providing assistance and protection for States Parties in the event of a chemical incident,^[28] promoting and supporting peaceful uses of chemistry, and scientific knowledge sharing and collaboration.^[29] Furthermore, the CWC bans the use of riot control agents (e.g., tear gas) as a weapon of war,^[30] but it does not provide for any restrictions on the use of riot control agents for law enforcement purposes^[31] (national laws of the individual states govern such use).

The history of chemical weapons focused on chemicals typically described as poisons (toxic substances) and toxic gases, while the CWC introduced a more precise definition, where "chemical weapons" are defined by one or more of the following criteria:^[32]

- Toxic chemicals and their precursors, except where intended for purposes not prohibited under this Convention [the CWC], as long as the types and quantities are consistent with such purposes;

- Munitions and devices, specifically designed to cause death or other harm through the toxic properties of those toxic chemicals specified in point (a) above, which would be released as a result of the employment of such munitions and devices;
- Any equipment specifically designed for use directly in connection with the employment of munitions and devices specified in point b above.

Criterion (a) is a complete prohibition of “toxic” chemicals and their precursors, unless that chemical has a legitimate use (and any state possessing that toxic chemical can show that the amounts it possesses are consistent with that legitimate use). Criteria (b) and (c) are also important as they indicate a chemical weapon does not need to be a discrete chemical substance; it can also be equipment or munitions used in the weaponization of that chemical.

Applying criterion (a) required the drafters of the CWC to define the term “toxic chemical”:

“Any chemical which through its chemical action on life processes can cause death, temporary incapacitation or permanent harm to humans or animals. This includes all such chemicals, regardless of their origin or of their method of production, and regardless of whether they are produced in facilities, in munitions or elsewhere.” ^[33]

It follows that when referring to WMDs, under international law, chemical weapons are specifically chemicals whose toxic properties are used to harm humans and animals, which excludes incendiary chemicals, explosive chemicals, and herbicides from being considered “chemical weapons” (unless these chemicals are used in a manner that intentionally exploits their toxic properties against humans or animals).

The History of Chemical Weapons and their Prohibition in Asia-Pacific

The Asia-Pacific region has been exposed to the development and use of chemical weapons by both state and non-state actors over the past century. This section of the paper will discuss this history of chemical weapon usage and the participation of states from the region in the global chemical weapons prohibition regime codified in the 1993 CWC. It will focus on chemical weapons programs and use by Imperial Japan, the United States, the Former Soviet Union (FSU), the People’s Republic of China, the ROK, and the DPRK. In addition, the most notorious case of non-state actor use of chemical weapons, by the Japanese Aum Shinrikyo cult, is briefly presented.

Of the eight states that have declared possession of chemical weapons to the OPCW, ^[34] three are regional states: the United States, Russia (declaring the stockpile of the FSU), and the ROK. However, the history of 20th century chemical warfare saw another regional power, Imperial Japan, use chemical weapons during the first half of the 20th century. The Japanese Imperial Forces had produced a number of chemical weapon agents, including phosgene, mustard, and lewisite. Before and during the Sino-Japanese war some of these were used in China. At the end of the war Japan’s chemical weapons in China, estimated at about 700,000 munitions, were dumped into rivers or buried. “Most of the Abandoned Chemical Weapons (ACW) in China are buried in the Haerbaling District of the City of Dunhua, Jilin Province.”¹⁸ With the entry into force of the CWC in 1997, Japan has assumed responsibility for destroying the chemical weapons it abandoned on Chinese territory. This process began in 2010^[35] and, given the large number of chemical munitions involved, is going to last for some more years to come.

Apart from the abandoned chemical weapons left behind on its territory, China only declared to the OPCW that it had destroyed all its past chemical weapon production facilities (CWPFs) and only conducts defensive Chemical Weapons (CW) research, which is permitted under the CWC. While

China never declared that it transferred chemical weapons to another state in the past, during Albania's chemical weapon destruction process some chemical munitions were discovered with Chinese markings on them.[36] While this would be consistent with Albania not having declared a CWPf, the origin of some of its chemical munitions was never fully clarified.

The United States amassed the world's second largest declared chemical weapons stockpile with over 28,000 metric tonnes of CW produced and located in several different CW storage facilities (CWSFs). Due to legislation passed by the US Congress, CW destruction facilities (CWDF) had to be built at each of the CWSFs. While the largest part of the US CW stockpile has been verifiably destroyed, protests against some of the planned destruction technologies led to delays in the destruction process at two CWDFs.[37] Currently, the completion of CW destruction in the last two remaining facilities - Pueblo, Colorado and Blue Grass, Kentucky - are scheduled for 2023.[38]

The FSU accumulated the world's largest declared chemical weapons stockpile of 40,000 metric tonnes of nerve and blister agents in bulk storage as well as munitions, these were spread over seven CWSFs. Like all other possessor states, Russia, as successor to the FSU was unable to meet the destruction deadline of April 2007, as contained in the CWC. With the assistance of the United States and other Western states the Russian Federation completed destruction of the declared FSU chemical weapon stockpile in September 2017.[39] However, Russia has been accused of being behind two assassination attempts involving the use of military-grade nerve agents in 2018[40] and 2020,[41] and some Western states believe that Russia has not fully declared or stopped its entire chemical weapons program.[42],[43] While the Western states have expressed condemnation of Russia for these incidents, mechanisms within the CWC to address non-compliance have been invoked only to a limited extent.[44]

An officially unidentified chemical weapon possessor state known in OPCW publications as "A State Party" is widely understood to be ROK, which ratified the CWC in 1997 and declared its chemical weapon stockpile and a production facility.[45] According to one estimate the size of ROK's stockpile was 3,126 metric tonnes.[46] Following media reports, the ROK's military built and operated a CWDF to eliminate all chemical munitions at a site in Yeongdong Chungcheong.[47] The ROK completed destruction of its stockpile in July 2008 as the second possessor state to do so.[48]

The DPRK has neither signed nor ratified the CWC. However, in 1989 it acceded to the 1925 Geneva Protocol, which prohibits the use of chemical and biological weapons, but not their development, production, or storage. Estimates by the United States and ROK authorities of a DPRK chemical weapons stockpile have varied over time, but since the 1990's seem to have revolved around the figure of 5,000 metric tonnes of various chemical warfare agents stockpiled, including highly toxic nerve agents.[49] It has also been reported that the DPRK has assisted other states, such as Syria, in their chemical weapon acquisition efforts.[50] Any efforts, pursued either bilaterally, or by the OPCW, to draw the DPRK closer to the CW prohibition regime have so far gone unanswered.

The notion of DPRK possessing a well-developed chemical weapons program, including so-called "binary chemical warfare agents," received further support when Kim Jong-nam, the half-brother of DPRK leader Kim Jong-un, was attacked with what subsequently was identified as the nerve agent VX at Kuala Lumpur airport in Malaysia in early 2017.[51] The attack was conducted by two female assailants (one a national of Indonesia and the other of Vietnam) who each smeared his face with a cloth, which has led experts to conclude that two components of a binary version of VX were applied. Kim Jong-nam died shortly after the attack on the way to hospital. This attack was met with international condemnation and the adoption of additional sanctions, for example, by the United States.[52] The DPRK denied any involvement and refused to cooperate with Malaysian authorities investigating the incident.[53] In 2019 the charges against the accused Indonesian citizen of the incident were dropped by Malaysian authorities. Subsequently, "the accused from Vietnam was

sentenced to three years and four months jail,” which concluded the legal proceedings resulting from the 2017 VX incident.[\[54\]](#)

The most notorious case of terrorist chemical weapon use in the Asia-Pacific was carried out by the Aum Shinrikyo doomsday cult during the mid-1990s. Two attacks with the nerve agent sarin were conducted in the city of Matsumoto in 1994 and in the Tokyo subway system in 1995 leading to the deaths of nineteen people and temporary hospitalizations for over a thousand more.[\[55\]](#) As investigators suspected that the first of the two incidents had been committed by the cult, and with cult members aware that the police were conducting a criminal investigation, the cult stopped running its CWPFs in early 1995. When a police raid appeared imminent, the cult hastily staged the Tokyo subway attack with sarin-filled plastic bags that were placed on three subway trains and punctured to allow sarin vapors to escape from the packaging. Besides the crude dispersal mechanism, another important aspect of Aum Shinrikyo employing chemical agents lies in their failure to weaponize biological agents—chemicals were their fallback option—after the difficulties they encountered with biological weapons proved insurmountable.[\[56\]](#) As the very detailed investigation after the attacks showed, Aum Shinrikyo had considerable resources at its disposal that were put into its chemical weapon program, which resulted in nineteen fatalities. This shows that chemical weapons do not automatically present an easy path for terrorists to induce mass casualties, albeit mass disruption was clearly a significant result of the attack.

While subsequent terrorist activities have not reached the level of disruption or casualties of the Aum Shinrikyo attacks of the 1990s, terrorism in the Asia-Pacific region continues to be a threat and some terrorist groups moving to the use of unconventional weapons, including chemical weapon agents, cannot be excluded.[\[57\]](#) An important group of states that seeks to prevent dual-use chemical materials and technologies from getting in the hands of proliferators or terrorists has become known as the Australia Group. Founded in the mid-1980s, three states from the Asia-Pacific region participate in the activities of the group: the United States, Japan, and the ROK.[\[58\]](#)

Science, Technology, and Chemical Weapons



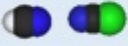
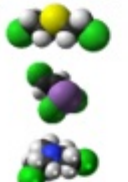
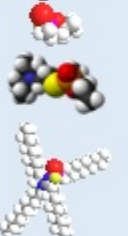
The CWC is a treaty underpinned by science and technology, which, for review of treaty implementation, and in the discussion of what the future may bring, is a central theme.[\[59\]](#) This section seeks to examine some of the scientific dimensions and how scientific and technological change are viewed in the context of chemical disarmament and the broader prohibition of chemical weapons.

Chemical weapons are defined by the toxidromes they induce.[\[60\]](#) Traditional military chemical agents fall into four classes: choking agents, blood agents, blister agents or vesicants, and nerve agents.[\[61\]](#)^[62] Table 1 describes these classes and provides representative examples of the chemicals they include. It also indicates the approximate order of increasing toxicity amongst the agents (nerve agents are the most toxic, requiring smaller exposure concentrations for lethal doses as compared to the other classes).

The Annex on Chemicals of the CWC is a set of schedules that lists chemicals associated with most of the traditional warfare agents and their precursors.²⁷ It should also be appreciated that a chemical weapon can be derived from any chemical exploited for its toxic properties—not just those that appear in the Annex. For example, chlorine is not listed in the Annex, yet has been implicated as a chemical weapon in the conflict in Syria.[\[63\]](#) The CWC Schedules were developed based on 20th century military arsenals with the specific purpose of providing a tool for manageable verification measures. There are three Schedules, each containing a set of sub-schedules representing specific chemicals or groups (“families”) of closely related substances.[\[64\]](#)

Schedule 1 is comprised of chemicals that have been developed, produced, stockpiled, or used as chemical weapons, notably vesicants and nerve agents (key nerve agent precursors, and the toxins ricin and saxitoxin^[65] are also included).²⁷ Schedule 2 lists chemicals that possess sufficient lethal or incapacitating toxicity to enable them to be used as chemical weapons and also chemicals that can serve as precursors for the toxic chemicals listed in Schedules 1 and 2.²⁷ Schedule 3 is comprised of chemicals that have been produced, stockpiled, or used as chemical weapons, or can serve as a precursors for chemicals in Schedules 1 and 2.²⁷

Table 1: Selected Chemical Warfare Agents^{61,62}

Class	Toxidrome	Representative Chemicals	Dispersal	CWC Schedules	Toxicity*
Choking Agents 	Absorption through lungs induces alveoli to secrete fluid that builds up in the lungs and chokes the victim.	Phosgene Chloropicrin Chlorine	Gas	3A01 3A04 (chlorine is unscheduled)	 Increasing
Blood Agents 	Absorbs through lungs and skin, and inhibits cellular oxygen use (e.g., preventing blood cells from transporting oxygen). Damages vital organs in central nervous, cardiovascular, and respiratory systems.	Hydrogen cyanide Cyanogen chloride	Gas	3A02 3A03	
Blister Agents (Vesicants) 	Absorbs through lungs and skin. Burns skin, mucous membranes, and eyes. Forms blisters on skin, windpipe, and lungs. Skin blisters are large, give rise to severe burns, and can be life-threatening. Exposure can lead to blindness and permanent respiratory tract damage.	Sulfur mustard Nitrogen Mustard Lewisite	Liquid, aerosol	1A04 1A05 1A06	
Nerve Agents 	Absorbs through lungs and skin, Inhibits the enzyme acetylcholinesterase, which leads to accumulation of the neurotransmitter acetylcholine in synapses between nerve cells, overstimulation of nerve signal transmission. Symptoms include lacrimation, salivation, sweating, blurred vision, headache, breathing difficulty, vomiting, seizures, loss of body control, muscle paralysis, and unconsciousness, which in sufficient exposure dosages can lead to death.	G-series (e.g. Sarin) V-series (e.g. VX) Novichoks Carbamates	Liquid, aerosol	1A01 1A02 1A03 1A13 1A14 1A15 1A16	

* The toxicity scalar is illustrative, there can be overlaps between classes when comparing specific chemicals.

Unlike the Schedule 1 chemicals, many Schedule 2 and 3 chemicals have significant economic importance, and some are actually used to produce consumer products,^[66] this illustrates one of the difficulties with banning chemical weapons. Industrial facilities that produce chemicals and many industrial chemicals themselves are dual-use in nature and can be used for chemical weapons programs, which is why the CWC's verification regime includes inspections of chemical production

facilities that produce discrete organic chemicals not found in the schedules.[67]

While the CWC bans riot control agents for use in warfare, it does not list or identify these agents. Rather, it only provides criteria: a riot control agent is: “any chemical not listed in a Schedule, which can produce rapidly in humans sensory irritation or disabling physical effects which disappear within a short time following termination of exposure”.[68] OPCW’s Scientific Advisory Board (SAB) provided non-binding guidance on chemicals that could conform to these criteria,[69] but conformity can also depend on factors broader than the identity of the chemical. These include exposure duration and concentration, physical surroundings and environmental conditions, and the underlying health of those exposed.[70]

Animals, plants, fungi, and microbes can also produce toxic substances; these are referred to as biological toxins.[71] Chemicals found in living systems that regulate life processes (bioregulators), are also potentially toxic,[72] although weaponization of bioregulators presents a number of difficulties.[73] Being chemicals, toxins and bioregulators are subject to the restrictions of the CWC if used for prohibited purposes, while also being considered biological toxins if used for prohibited purposes under the BTWC, creating an overlap of prohibitions for “mid-spectrum agents” between the two treaties (Figure 1). The presence of ricin (a plant toxin) and saxitoxin (produced by cyanobacteria and responsible for paralytic shellfish poisoning) on the CWC Schedules illustrates the treaty’s purview in this realm. However, many other toxins with potential for harmful uses exist.⁷² Given the potential to acquire toxins from natural sources, these substances are commonly considered as security threats, as illustrated by a 2019 foiled plot to use the toxin abrin in homemade bombs in Indonesia.[74]

The CWC sets down obligations intended to be of an unlimited duration,[75] while the pace of scientific discovery, and with it our perception of the boundaries of scientific disciplines, continues to advance.[76] Scientific developments, especially in the field of chemistry, can bring great benefits to humankind, and under the provisions of the CWC, States Parties are obliged to ensure chemistry is not used in violation of the Convention. Yet, continued discoveries in chemistry continuously raise security concerns.[77]

The number of known chemicals increases by millions of substances every year, while the CWC’s Annex on Chemicals has only seen one update since 1993 when it was originally agreed on. This was the addition of four groups of new types of nerve agents following the Skripal poisoning in 2018.⁴⁰ The new schedules (1A13-1A16) entered in force in June 2020.[78].[79],[80]

As modern science reveals more about the molecular world underpinning life processes, new types of toxic chemicals tailored to attacking specific biological functions are a potential outcome.[81] The development of nanomedicines targeting specific types of cells, tissues, and organs to deliver payloads of therapeutic or even toxic chemicals (which is effectively how nanomedicine-based chemotherapy agents function) elicit similar concerns.[82] There are clear pathways to poisoning and harm. There are also practical considerations, as the properties of a chemical intended to be weaponized may differ from those required of a chemical to be used for medical purposes under controlled conditions. Development of nanomedicines for chemotherapy has revealed examples of toxic chemicals targeted against specific types of cells (tumors) that are not always more effective than untargeted (and less expensive) approaches.[83] This in turn introduces a degree of uncertainty as to the risk of such approaches as chemical weapons.

Figure 1: Biochemical Threat Spectrum from Chemical Warfare Agents (CWA) to Biological Warfare Agents (BWA)[84]

Note: The chemical and biological agents listed are intended to be illustrative, not comprehensive. Solid borders between the example columns are absent in the representation as this is meant to illustrate a continuum.

Covered by Biological Chemical Weapons Convention (CWC, Article II)					
Poisons (Toxic Chemicals)				Infectious Agents	
Classical CWA	Other Toxic Chemicals	Small Molecule Toxins and Bioregulators	Large Molecule (Protein) Toxins	Genetically Modified BWA	Classical BWA
Chlorine	Industrial Chemicals	Mid-spectrum Agents		Tailored and modified Bacteria and Viruses	Bacteria
Phosgene		Conotoxins	Botulinum Toxins		Viruses
Sulfur Mustard	Agricultural Chemicals				Saxitoxin
Nitrogen Mustard	Pharmaceuticals	Tetrodotoxin	Ricin		Anthrax
Lewisite	Central Nervous System-Acting Chemicals	Substance P	Staphylococcal enterotoxin B		Plague
G- and V-Series Nerve Agents		Neurokinin A			Small Pox
					Tularemia
Covered by Biological and Toxins Weapons Convention (BTWC, Article I)					

Solid borders between the example columns are absent in the representation as this is meant to illustrate a continuum. The application of chemicals intended to incapacitate has led to concerns on the use of pharmaceutical-based substances that act on the central nervous system (CNS).^[85] Aerosolized dispersal of chemicals intended to incapacitate by Security forces that ended the Dubrovka Theater Siege in Moscow in 2002^[86] resulted in fatalities among both hostages and terrorists. In the aftermath, an intensive review began within OPCW's SAB^{86, [87]} alongside equally intensive deliberations among CWC States Parties on security concerns of chemicals intended for use in incapacitation roles, especially in regard to law enforcement usage.^[88] In 2021, the States Parties adopted a decision by vote to "affirm that CWC States Parties understand that the use of aerosolized CNS-acting chemicals is inconsistent with law enforcement as a purpose not prohibited by the Convention".^{[89], [90]} Pertinent to the debates leading up to this decision have been suggestions that development of aerosolized incapacitating chemicals for law-enforcement purposes may be a back-door entryway for the development of new chemical warfare agents.^[91]

While the outcome of the debate on the CNS-acting chemical issue was a decision of the States Parties, this was not a decision of consensus. At the vote, 128 States were present, 85 voted yes, 10 voted no, and 33 abstained. There were 14 Asia-Pacific States present, Russia and China, who had previously called for further discussion on the issue,^{[92], [93]} voted against the decision, while Indonesia and Vietnam abstained.⁹¹ Australia, Canada, Japan, Malaysia, the Marshall Islands, Palau, Philippines, ROK, Singapore, and the USA voted in favor.⁹¹

A chemical weapon (like any weapon system or technology) requires multiple components and considerations for use. This is seen within the CWC definition of a chemical weapon that covers both toxic chemicals and equipment for deploying the chemicals as weapons, even when the equipment contains no toxic chemicals. An advanced chemical weapons capability requires more than chemicals. Capabilities to produce and dispose of chemicals (chemical engineering), to protect against indiscriminate chemical effects (protective equipment, decontamination, and medical countermeasures), and to engineer and design the delivery systems are also necessary. It is a highly transdisciplinary endeavor.^[94] Maintaining the chemical weapons programs of the Cold War required significant resources, as has the destruction efforts required by the CWC.^[95] Such

expertise and resource requirements might create a barrier to entry for initiating a traditional 20th Century state-level program. However, events in Syria and the assassination scenarios witnessed over the last few years^{40,41,51} illustrate novel approaches to the weaponization of chemicals. This draws attention once more to scientific developments that are potentially enabling for such purposes.

It is estimated that there are more possible chemicals with drug-like effects than there are atoms in the universe,^[96] an observation that does little to ease security concerns over new chemical discoveries. From a scientific perspective, exploring this “chemical space” to find new chemicals with superior properties to those we have now (as materials, medicines, and more) is a source of excitement for societal benefit. In pursuing these benefits, chemistry, which like so many scientific fields, embraces emerging technologies such as artificial intelligence and automation to aid in the discovery process,^[97] and this gives us innovation, a faster pace of scientific development, and further security concerns.

Research involving chemical warfare agents in pursuit of better and more effective protective equipment, decontaminants, and medical countermeasures is on-going.^{82,97,[98],[99]} The transdisciplinary nature of scientific discovery is as important here as it is for developing weapons. Much of the expertise and research on more effective ways to counter chemicals weapons takes place in well-resourced state-funded laboratories, and the OPCW facilitates a network of Designated Laboratories across member states.^[100] These laboratories develop analysis methods to detect chemical agents to support verification, share procedures, and collectively participate in proficiency testing.^{[101][102]} The laboratory network serves to strengthen the CWC’s verification regime (these laboratories have been central to the analysis of samples and independent reporting of results from chemical weapon related fact-finding).^[103] Additionally, the network exemplifies international scientific collaboration (a norm of the CWC). States in the Asia-Pacific with Designated Laboratories include Australia, China, ROK, Russia, Singapore, and the United States. Other regional States also have laboratories with capabilities for countering chemical weapons (most notably, Japan^[104] and Malaysia^[105]), but these laboratories are outside of the OPCW network.

New scientific developments with relevance to the CWC may also emerge from scientific communities beyond the specialized laboratories. Here, the chemical industry is not only a key driver of innovation, but it is also a key stakeholder in upholding the CWC’s verification regime.^[106] Industrial chemistry also facilitates the diffusion of chemical expertise and knowledge on a global scale. Asia-Pacific states have a significant chemical industry presence. Globally, chemical production and sales is dominated by China (responsible for more than 44% of 2020 global chemical sales), with the United States (12.3%), Japan (4.1%), the ROK (2.9%), and Russia (1.1%) also in the top ten chemical producing nations.^[107]

Overall scientific output from Asia-Pacific mimics trends seen in global chemical production and dominates global scientific outputs (across all fields and sectors). The greatest amounts of global research and development funding are seen in China, USA, and Japan, with ROK and Russia also in the top ten.^[108] Research and development funding as a proportion of a State’s GDP is the highest worldwide for the ROK (4.35% in 2021 as compared to 2.88% for the US and 1.98% for China).¹¹¹ In 2020, China produced the greatest amount of global scientific publications (23% of the world total, with more than 669,000 produced), followed by the United States (15.5%). Japan (3.4%), Russia (3.1%), and the ROK (2.5%) are also in the top ten.^[109] Science is also international with collaborations across regions and states entrenched within the scientific enterprise (in both industrial and academic sectors). For the 2020 publication output, 22% of publications from Chinese scientists were co-authored with scientists from at least one other state. For scientists from the United States, 40% of 2020 scientific publications included international coauthors (26% were co-

authored with scientists from China, 5.3% with scientists from Japan, and 4.5% with scientists from ROK).¹¹²

The scale of the scientific enterprise is daunting when considering how to answer calls for monitoring science to ensure states parties to the CWC or BTWC are not caught off guard. There are many scientific discoveries that could enable new ways to access, produce, and/or weaponize toxic chemicals, which in turn might be an entry-point for non-state actors and/or terrorists. Yet, the use of any technology, old or new, requires certain expertise, resources, and tacit knowledge, and especially for new and emerging technologies there will always be uncertainties with respect to the potential risk of harmful use.[\[110\]](#)

While the prospects of scientific advances for proliferation and lowering barriers for use of chemical weapons raise concerns, recent chemical weapons attacks have included chlorine gas (a chemical known for more than 200 years),[\[111\]](#) crude preparations of sulfur mustard,[\[112\]](#) setting a sulfur mine on fire to generate toxic gases,[\[113\]](#) and assassinations scenarios with nerve agents (in one case by wiping binary precursors in succession onto an individual's face⁵¹). These observations are noteworthy in that they are not employing cutting edge scientific and technological advances. Furthermore, low technology approaches to chemical attacks (including the use of industrial chemicals rather than traditional chemical warfare agents)[\[114\]](#) are considered significant security threats.

The medical countermeasures currently available for nerve agents were introduced in the 1950s and 1960s, but the wealth of research demonstrating potential improvements has not been translated into operational use.^{82,101,102} Similarly, despite advanced understanding of molecular biology, the mechanism through which sulfur mustard forms blisters is not fully understood,⁸² limiting effectiveness of available treatments. There is need for continued research and development to counter and respond to chemical weapons, as well as a need to maintain skills and knowledge to counter the chemical weapons of the past.

Access to scientific expertise and enhanced technical capability plays an important role in countering chemical threats. There is need to be able to recognize, prevent, and mitigate the effects of chemical attacks and unexpected uses of new technologies. This is reflected in recommendations from the OPCW SAB for drawing on scientific advances to strengthen implementation of the CWC, respond to chemical threats both familiar and unknown, and to build greater confidence in verification and compliance.^{97,115} However, just as certain expertise, resources, and tacit knowledge are needed to weaponize chemicals, these same considerations are also necessary for realizing the capabilities needed to effectively counter the proliferation of chemical weapons. States with greater science and technology resources are expected to be better equipped to draw upon more advanced expertise and capability.

Current Status and Future Prospects

Possession of chemical weapons by states in the Asia-Pacific has decreased significantly over the past two decades, thereby reducing the probability that such weapons would be used in a traditional war between States. However, a big unknown is the DPRK. Both the timing of a DPRK accession to the CWC and the size of any chemical weapons stockpile that it would declare in such a scenario remain a matter of speculation. If the DPRK accedes to the CWC, then the standard operating procedures for possessor states, as spelled out in the treaty, would not likely apply. Rather, a much higher involvement of the OPCW and, potentially, states from the region would likely be required to ensure the safe and irreversible destruction of DPRK chemical weapons under international verification. In preparing for this contingency, the case of dismantling the declared Syrian chemical weapons stockpile may offer lessons.[\[116\]](#)

While the prospect of a traditional military conflict involving chemical weapons among CWC States Parties seems unlikely, this has not prevented malign uses of chemicals by states as illustrated by the recent high profile poisonings with nerve agents that have been linked to Asia Pacific states. In addition, there are larger concerns within security communities of the erosion of the norms against chemical weapons upon which the CWC is founded. Future prospects for overcoming these issues rests with the political will of the states involved, including the will to use tools available in the CWC for addressing non-compliance.

Considering the recent uses of chemical warfare agents, the threat of chemical terrorism whether by non-state actors or those with state sponsorship is a real possibility. A number of Asia-Pacific states have experienced acts of terrorism and/or have active insurgencies.^[117] While the majority of reported terrorist attacks are not chemical, the specter of chemical terrorism looms large and is not unknown. A recent study using data from the Global Terrorism Database identified 321 chemical attacks from 1970-2015, while South Asia was the region of the greatest number of these incidents, chemical attacks have also occurred in Australia and Oceania, East Asia, Eastern Europe, North America, and South East Asia, all of which are regions home to Asia Pacific States.^[118] Measures to mitigate and prevent chemical terrorism include as a basis the implementation of CWC provisions and their prohibitions into national laws and regulations that can be used to bring perpetrators to justice. In addition, strengthening chemical security measures in sectors ranging from healthcare and emergency medicine,^[119] to chemical industry and civil defense, can aid in dealing with such terrorist attacks should they occur.

Non-traditional chemical threat scenarios represent another potential route for intentional chemical attacks. The large industrial base present in the Asia-Pacific presents potential targets for attacks on infrastructure that could result in chemical releases. Such attacks might also occur through cyber vulnerabilities, which requires non-traditional considerations toward chemical security in general.^[120]

The Asia-Pacific is home to five of the world's top ten most highly resourced and funded states for scientific and technological research and development, as well as five of the top ten chemical producing states. Recent chemical incidents have demonstrated that low technology and non-traditional chemical threat approaches pose significant challenges. For traditional 20th century chemical weapons programs, the components and formats of chemical weapons systems are well understood, and key commodities and materials for their production are found under export control regimes to reduce proliferation risk (for example control lists from the Australia Group^[121] and Wassenaar Arrangement^[122] that include chemical agents and their precursors). Low technology approaches, however, can draw upon non-traditional components and commonly available chemicals to enable attacks. These approaches challenge how to think about preventing the re-emergence of chemical weapons and preparedness for countering chemical attacks in a 21st century world. The chemical attacks we have witnessed (and those likely to come in future) are not following the doctrines of the Cold War that influenced negotiation and drafting of the CWC.

As the CWC approaches its 25th anniversary in April 2022 (and beyond), the prohibition of chemical weapons will increasingly benefit from science and technology as a source of innovation and opportunity to better detect, prevent, and/or respond to chemical threats. The OPCW SAB has provided useful views from where guidance can be drawn,^{97,118} and scientific contributions from Asia-Pacific alongside collaboration among (and beyond) the regional states will certainly have a significant role. Ultimately, however, it is the actions and decisions of the States Parties of the CWC, not the science and technology they possess, that will drive success in prohibiting chemical weapons and preventing their re-emergence.

III. ENDNOTES

[1] In this narrative, we focus on the internationally recognized states of Asia-Pacific that make up the Pacific Rim, excluding Central and South America and New Zealand. These are: Australia, Canada, China, Democratic People's Republic of Korea (DPRK), Fiji, Indonesia, Japan, Kiribati, Marshall Islands, Malaysia, Micronesia, Nauru, Palau, Papua New Guinea, Philippines, Republic of Korea (ROK), Russia, Samoa, Singapore, Solomon Islands, Tonga, Tuvalu, United States, Vanuatu, and Vietnam.

[2] A. Mayor. *Greek Fire, Poison Arrows & Scorpion Bombs: Biological and Chemical Warfare in the Ancient World*; Overlook Press: New York, 2003.

[3] For a history of 20th century CBW use see (a) J. Tucker. *War of Nerves. Chemical Warfare from World War I to Al Qaeda*, New York: Pantheon, 2006. (b) *The Problem of Chemical and Biological Warfare, Volume 1: The Rise of CB Warfare*, SIPRI, Stockholm 1971, <https://www.sipri.org/publications/2000/problem-chemical-and-biological-warfare>.

[4] "Army Talks About Napalm Chemical Corps reveals some technical information on the chemistry and manufacture of incendiary gels". *Chem. Eng. News* 1954, 32, 27, pp. 2690-2692. DOI: 10.1021/cen-v032n027.p2690.

[5] M. Lumsden. *Incendiary weapons*. Stockholm International Peace Research Institute, MIT Press, Cambridge, Mass., 1975, pp. 227-249.

[6] Kim Coleman, *A History of Chemical Warfare*. Palgrave Macmillan, United Kingdom, 2005. DOI 10.1057/9780230501836.

[7] J. Kelly. *Gunpowder: Alchemy, Bombards, And Pyrotechnics: The History of The Explosive That Changed The World*. Atlantic Press, 2004.

[8] G. I. Brown. *The Big Bang: A History of Explosives*. Sutton: Stroud, UK, 1998. ISBN 0-7509-23-1-X.

[9] S. Everts. "When Chemicals Became Weapons of War." *Chem. Eng. News* 2015, 93(9), 21; <https://chemicalweapons.cenmag.org/when-chemicals-became-weapon-o-war/#:~:text=The%20release%20of%20poison%20gas,Haber%2C%20the%20weapon's%20main%20advocate>

[10] J. McManus, K. Huebner. "Vesicants." *Critical Care Clinics*. 2005, 21(4), pp. 707-18. DOI: 10.1016/j.ccc.2005.06.005.

[11] S. Costanzi, J. H. Machado, M. Mitchell. "Nerve Agents: What They Are, How They Work, How To Counter Them". *ACS Chem. Neurosci*. 2018, 9 (5), pp. 873- 885. DOI: 10.1021/acscchemneuro.8b00148.

[12] J. Stellman, S. Stellman, R. Christian, T. Weber, C. Tomasallo. "The extent and patterns of usage of Agent Orange and other herbicides in Vietnam." *Nature* 2003, 422, pp. 681-687. DOI: 10.1038/nature01537.

[13] International Declaration concerning the Laws and Customs of War. Brussels, 27 August 1874; available at: <https://ihl-databases.icrc.org/ihl/INTRO/135>

[14] (a) Convention (II) with Respect to the Laws and Customs of War on Land and its annex: Regulations concerning the Laws and Customs of War on Land. The Hague, 29 July 1899; available at: <https://ihl-databases.icrc.org/ihl/INTRO/150>. (b) Convention (IV) respecting the Laws and Customs of War on Land and its annex: Regulations concerning the Laws and Customs of War on Land. The Hague, 18 October 1907; available at: <https://ihl-databases.icrc.org/ihl/INTRO/195>

[15] The USA did not ratify the declaration on the use of projectiles for delivering asphyxiating or deleterious gases.

[16] S. Everts. A Brief History of Chemical War: For more than 2,000 years human ingenuity has turned natural and synthetic poisons into weapons of war. *Distillations* May 11, 2015;

<https://www.sciencehistory.org/distillations/a-brief-history-of-chemical-war#:~:text=Three%20substances%20were%20responsible%20for,%2C%20phosgene%2C%20and%20mustard%20gas>

[17] Protocol for the Prohibition of the Use of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare. Geneva, 17 June 1925; available at: <https://ihl-databases.icrc.org/applic/ihl/ihl.nsf/INTRO/280>

[18] (a) Japanese Chemical Weapons Program, Federation of American Scientists; <https://fas.org/nuke/guide/japan/cw/>. (b) A detailed Japanese report on chemical weapon use in China recently became available: <https://www.japantimes.co.jp/news/2019/07/08/national/history/detailed-report-documents-japans-us-e-nerve-agents-second-sino-japanese-war/>

[19] M. Meselson. "Tear Gas in Vietnam and the Return of Poison Gas". *Bulletin of the Atomic Scientists* 2015, 27(3), pp. 17-19. DOI: 10.1080/00963402.1971.11455334.

[20] *Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction*; <http://disarmament.un.org/treaties/t/bwc>

[21] *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction*; Organisation for the Prohibition of Chemical Weapons; www.opcw.org/chemical-weapons-convention/

[22] Organisation for the Prohibition of Chemical Weapons; www.opcw.org

[23] Organisation for the Prohibition of Chemical Weapons Member States; www.opcw.org/about-us/member-states

[24] The Nobel Peace Prize 2013. <https://www.nobelprize.org/prizes/peace/2013/summary/>

[25] (a) Organisation for the Prohibition of Chemical Weapons by the Numbers; www.opcw.org/media-centre/opcw-numbers. (b) Further details on summary statistics of implementation of the CWC can be found in OPCW Annual Reports, available at: www.opcw.org/resources/documents/annual-reports

[26] Fact Sheet 5: Three Types of Inspections; Organisation for the Prohibition of Chemical Weapons: The Hague, November 2017.

[27] Annex on Chemicals. *Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction*; Organisation for the Prohibition of Chemical Weapons. The Hague, 2020;

www.opcw.org/chemical-weapons-convention/annexes/annex-chemicals/annex-chemicals

[28] Organisation for the Prohibition of Chemical Weapons Capacity Building (Assistance and Protection); www.opcw.org/resources/capacity-building. See also CWC Article X: Assistance and Protection Against Chemical Weapons;

www.opcw.org/chemical-weapons-convention/articles/article-x-assistance-and-protection-against-chemical-weapons

[29] Organisation for the Prohibition of Chemical Weapons Capacity Building (International Cooperation); www.opcw.org/resources/capacity-building. See also CWC Article XI: Economic and Technological Development;

www.opcw.org/chemical-weapons-convention/articles/article-xi-economic-and-technological-development

[30] See CWC Article I: General Obligations

www.opcw.org/chemical-weapons-convention/articles/article-i

[31] For “Purposes Not Prohibited,” see: Definitions and Criteria, paragraph 9;

www.opcw.org/chemical-weapons-convention/articles/article-ii-definitions-and-criteria

[32] See CWC Article II: Definitions and Criteria, paragraph 1;

www.opcw.org/chemical-weapons-convention/articles/article-ii-definitions-and-criteria

[33] IBID, paragraph 2.

[34] The following states have declared chemical weapons to the OPCW: Albania, India, Iraq, Libya, Syria, Russia, ROK, and the United States. See P. Walker. “Three Decades of Chemical Weapons Elimination: More Challenges Ahead.” *Arms Control Today* 2019;

<https://www.armscontrol.org/act/2019-12/features/three-decades-chemical-weapons-elimination-more-challenges-ahead>. As of November 2020, all states except the United States have completed the destruction of the declared stockpiles. The United States estimates completion in 2023. Further information on the US chemical weapon destruction program is available from: Program Executive Office, Assembled Chemical Weapons Alternatives; <https://www.peoacwa.army.mil/>

[35] *Report of the OPCW on the Implementation of the Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction in 2010*, C-16/4, OPCW: The Hague, 29 November 2011;

www.opcw.org/sites/default/files/documents/CSP/C-16/en/c1604_e_.pdf

[36] M. V. Tompkins, Albania’s Chemical Weapons Con, *The Nonproliferation Review*, 2009, Vol.16, No.1, pp. 65-77; Ivan Lebedev, “Allegedly Chinese-Made Chemical Weapons Found in Albania,” *ITAR-TASS News Agency*, January 11, 2005.

[37] See *Chemical Weapons: Destruction Schedule Delays and Cost Growth Continue to Challenge Program Management*,

GAO-04-634T, United States Government Accounting Office, 2004;

<https://www.gao.gov/products/gao-04-634t>.

[38] See the US government implementing agency's vision statement at <https://www.peoacwa.army.mil/about-peo-acwa/>.

[39] "OPCW Marks Completion of Destruction of Russian Chemical Weapons Stockpile"; www.opcw.org/media-centre/news/2017/10/opcw-marks-completion-destruction-russian-chemical-weapons-stockpile

[40] M. Peplow. "Nerve agent attack on spy used 'Novichok' poison Chemical weapon used in U.K. assassination attempt was developed by Soviet Union during Cold War" *Chem. Eng. News* 2018, 96(12); <https://cen.acs.org/articles/96/i12/Nerve-agent-attack-on-spy-used-Novichok-poison.html>.

[41] R. Stone. "How German military scientists likely identified the nerve agent used to attack Alexei Navalny", *Science* 8, September 2020; DOI: 10.1126/science.abe6561.

[42] (a) S. Costanzi, G. D. Koblenz, "Controlling Novichoks after Salisbury: revising the Chemical Weapons Convention schedules." *The Nonproliferation Review*, 2019, 26(5-6), pp. 599-612. DOI: 10.1080/10736700.2019.1662618. (b) "EU imposes sanctions on Kremlin chiefs over Alexei Navalny poisoning", *The Guardian*, 15 October 2020; <https://www.theguardian.com/world/2020/oct/15/eu-announces-sanctions-against-kremlin-chiefs-over-alexei-navalny-poisoning>

[43] (a) US Department of State, *Compliance With the Convention of the Prohibition of the Development, Production, Stockpiling, and Use of Chemical Weapons and on Their Destruction. Condition (10)(C) Report*, Washington, D.C., June 2020; <https://www.state.gov/wp-content/uploads/2020/06/2020-10C-Report-Unclassified-Version-for-H.pdf>. (b) US Department of State, *Compliance With the Convention of the Prohibition of the Development, Production, Stockpiling, and Use of Chemical Weapons and on Their Destruction. Condition (10)(C) Report*, Washington, D.C., April 2021; <https://www.state.gov/wp-content/uploads/2021/04/2021-Condition-10-c-Report.pdf>.

[44] Only the clarification procedure in Article IX (2) has been used. O.Meier, A. Kelle, "The Navalny poisoning: Moscow evades accountability and mocks the Chemical Weapons Convention"; <https://thebulletin.org/2021/10/the-navalny-poisoning-moscow-evades-accountability-and-mocks-the-chemical-weapons-convention/> Additional provisions include challenge inspections (CWC Article IX), investigations of alleged use (article X), measures to ensure compliance (CWC Article XII), and procedures for settlement of disputes (CWC article XIV); www.opcw.org/chemical-weapons-convention

[45] *SIPRI Yearbook 1998*, p. 461, footnote 19; <https://www.sipri.org/yearbook/archive>

[46] See <https://www.globalsecurity.org/wmd/world/rok/cw.htm>

[47] *Report: Korean Army Built Factory to Destroy Chemical Weapons*, Deutsche Presse-Agentur, 9 May 2000, quoted at <https://www.nti.org/learn/countries/south-korea/>

[48] *SIPRI Yearbook 2009*, pp. 419-20; <https://www.sipri.org/yearbook/archive>

[49] International Crisis Group, *North Korea's Chemical and Biological Weapons Programs*, Asia Report N°167, 18 June 2009; www.crisisgroup.org

[50] Ibid, pp. 9-10; M. Schwirtz, "UN Links North Korea to Syria's Chemical Weapons Program," *The New York Times*, 27 February 2018; <https://www.nytimes.com/2018/02/27/world/asia/north-korea-syria-chemical-weapons-sanctions.html>

- [51] D. Bradle. "VX nerve agent behind Kim Jong-Nam's murder," *Chemistry World*, 24 February 2017; <https://www.chemistryworld.com/news/vx-nerve-agent-behind-kim-jon-nams-murder/2500460.article#/>
- [52] "OPCW Executive Council Condemns Chemical Weapons Use in Fatal Incident in Malaysia"; <https://www.opcw.org/media-centre/news/2017/03/opcw-executive-council-condemns-chemical-weapons-use-fatal-incident>;
- [53] C. Vestergaard, *Chemical Assassination: The Role of International Organizations*, Commentary, 2 March 2017, available at: <https://www.stimson.org/2017/chemical-assassination-role-international-organizations/>.
- [54] Malaysia: *Statement by H.E. Ambassador Ahmad Nazri Yusof Permanent Representative of Malaysia to the OPCW at the Ninety-First Session of the Executive Council*, OPCW: The Hague, 10 July 2019, p..2;
- <https://www.opcw.org/resources/documents/executive-council/ec-91>
- [55] J. Tucker, *War of Nerves. Chemical Warfare from World War I to Al-Qaeda*, New York: Pantheon Books 2006, pp. 333ff.
- [56] See M. Leitenberg, "The Experience of the Japanese Aum Shinrikyo Group and Biological Agents," in B. Roberts (Ed.) *Hype or Reality: The "New Terrorism" and Mass Casualty Attacks*, Alexandria, VA: CBACI, pp. 159-170.
- [57] S. Mullins. "Terrorism in the Indo-Pacific: The Year Gone By and the Road Ahead." *Journal of Indo-Pacific Affairs*, Summer 2020, 4-35; <https://media.defense.gov/2020/Jun/08/2002311969/-1/-1/1/MULLINS.PDF>.
- [58] For a listing of States participating in the Australia Group, see:
- <https://www.dfat.gov.au/publications/minisite/theaustraliagroupnet/site/en/participants.html>.
- [59] (a) J. E. Forman, C. M. Timperley. "Chemical Disarmament in a Technologically Evolving World." In *Responsible Conduct in Chemistry Research and Practice: Global Perspectives*; E. T. Contis, A. Campbell, D. Phillips, B. Miller, L. Brown, L., (Eds.); ACS Symposium Series; American Chemical Society: Washington, DC, 2018; Vol. 1288, pp. 3- 35. (b) J. E. Forman, C. M. Timperley, S. Sun, D. van Eerten. "Chemistry and Diplomacy." *Pure Appl. Chem.* 2018, 90(10), pp. 1507- 1525. DOI: 10.1515/pac-2018-0902.
- [60] G. R. Ciottone. "Toxidrome Recognition in Chemical-Weapons Attacks." *N Engl J Med* 2018; 378, pp. 1611-1620. DOI: 10.1056/NEJMr1705224.
- [61] "What is a Toxic Chemical?" Organization for the Prohibition of Chemical Weapons; www.opcw.org/work/what-chemical-weapon#:~:text=General%20Purpose%20Criterion%20E2%80%9393%20Intent,not%20prohibited%20by%20the%20Convention
- [62] S. Costanzi. "Chemical Warfare Agents." *Kirk-Othmer Encyclopedia of Chemical Technology* 2020; DOI: 10.1002/0471238961.0308051308011818.a01.pub3.
- [63] See for example: *First Report by the OPCW Investigation and Identification Team (IIT) Pursuant to Paragraph 10 of Decision C-SS-4/Dec.3 "Addressing the Threat From Chemical Weapons Use" Ltamenah (Syrian Arab Republic) 24, 25, and 30 March 2017*, S/1867/2020, 8 April 2020,

Organisation for the Prohibition of Chemical Weapons, The Hague;
www.opcw.org/sites/default/files/documents/2020/04/s-1867-2020%28e%29.pdf

[64] G. Pontes, J. Schneider, P. Brud, L. Benderitter, B. Fourie, C. Tang, C. M. Timperley, J. E. Forman. "Nomenclature, Chemical Abstracts Service Numbers, Isomer Enumeration, Ring Strain, and Stereochemistry: What Does Any of This Have to Do with an International Chemical Disarmament and Nonproliferation Treaty?" *Journal of Chemical Education* 2020, 97, pp. 1715–1730. DOI: 10.1021/acs.jchemed.0c00547.

[65] A. M. Sierra, R. Martinez-Alvarez. "Ricin and Saxitoxin: Two Natural Products That Became Chemical Weapons." *J. Chem. Educ.* 2020, 97(7), pp. 1707–1714. DOI: 10.1021/acs.jchemed.9b00841.

[66] *Most Traded Scheduled Chemicals 2022*. 2022, Organisation for the Prohibition of Chemical Weapons: The Hague, The Netherlands.
www.opcw.org/resources/declarations/most-traded-scheduled-chemicals-2022.

[67] See (a) CWC Article VI: Activities Not Prohibited Under this Convention;
www.opcw.org/chemical-weapons-convention/articles/article-vi-activities-not-prohibited-under-convention#:~:text=Article%20VI-Activities%20Not%20Prohibited%20Under%20this%20Convention,not%20prohibited%20under%20this%20Convention (b) Parts VI-IX of the CWC's Verification Annex;
www.opcw.org/chemical-weapons-convention/annexes/verification-annex/part-i-definitions

[68] See CWC Article II: Definitions and Criteria, paragraph 7;
www.opcw.org/chemical-weapons-convention/articles/article-ii-definitions-and-criteria

[69] (a) "Advice from Scientific Advisory Board of the Organisation for the Prohibition of Chemical Weapons on riot control agents in connection with the Chemical Weapons Convention." C. Timperley, J. Forman, P. Aas, M. Abdollahi, D. Benachour, A. Al-Amri, A. Baulig, R. Becker-Arnold, V. Borrett, F. Carino, C. Curty, D. Gonzalez, M. Geist, Michael; B. Kane, Z. Kovarik, R. Martinez-Alvarez, B. Mikulak, N. Mourao, S. Neffe, E. Noguiera, P. Ramasami, Ponnadurai; S. Raza, V. Rubaylo, A. Saeed, K. Takeuchi, C. Tang, F. Trifiro, F. van Straten, A. Suarez, F. Waqar, P. Vanninen, M. Zafar-Uz-Zamen, S. Vucinic, V. Zaitsev, M. Zina, S. Holen, F. Izzati; *RSC. Adv.* 2018, 8, 41731-41739. DOI: 10.1039/c8ra08273a. (b) *Response to the Director-General's Request to the Scientific Advisory Board to Provide Consideration on Which Riot Control Agents are Subject to Declaration Under the Chemical Weapons Convention*. SAB-25/WP.1, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands, 27 March 2017;
www.opcw.org/sites/default/files/documents/SAB/en/sab25wp01_e_.pdf

[70] (a) R. J. Haar, V. Iacopino, N. Ranadive, S. D. Weiser, M. Dandu. "Health impacts of chemical irritants used for crowd control: a systematic review of the injuries and deaths caused by tear gas and pepper spray." *BMC Public Health* 2017, 17, pp. 831. DOI: 10.1186/s12889-017-4814-6 (b) C. Rothenberg, S. Achanta, E. R. Svendsen, S. E. Jordt. "Tear gas: an epidemiological and mechanistic reassessment". *Ann N Y Acad Sci.* 2016, 1378(1), pp. 96-107. DOI: 10.1111/nyas.13141.

[71] (a) V. Pitschmann, Z. Hon. "Military importance of natural toxins and their analogs." *Molecules* 2016,

21, 556. DOI: 10.3390/molecules21050556. (b) B. G. Dorner, R. Zeleny, K. Harju, J A.

Hennekinne, P. Vanninen, H. Schimmel, A. Rummel; "Biological toxins of potential bioterrorism risk:

Current status of detection and identification technology." *Trends in Anal. Chem.* 2016, 85, 89-102. DOI: 10.1016/j.trac.2016.05.024.

[72] S. Bokan, Z. Orahovec Z. "An Evaluation of Bioregulators/Modulators as Terrorism and Warfare Agents." In *Technology for Combating WMD Terrorism*, P. J. Stopa, Z. Orahovec (Eds.), NATO Science Series (Series II: Mathematics, Physics and Chemistry), vol 174. Springer, Dordrecht, 2004. DOI: 10.1007/978-1-4020-2683-6_3.

[73] *Convergence of Chemistry and Biology: Report of the Scientific Advisory Board's Temporary Working Group*. SAB/REP/1/14, Organisation for the Prohibition of Chemical Weapons, 26 June 2014, The Hague, The Netherlands;
www.opcw.org/sites/default/files/documents/SAB/en/TWG_Scientific_Advisory_Group_Final_Report.pdf

[74] V. Arianti, "Biological Terrorism in Indonesia," *Diplomat*, 20 November 2019.

[75] See CWC Article XVI: Duration and Withdraw, paragraph 1;
www.opcw.org/chemical-weapons-convention/articles/article-xvi-duration-and-withdrawal

[76] G. M. Whitesides. "Reinventing Chemistry." *Angew. Chem., Int. Ed.* 2015, 54, pp. 3196-3209.

[77] *Preventing Chemical Weapons: Arms Control and Disarmament as the Sciences Converge*; M. Crowley, M. Dando, L. Shang (Eds.); Royal Society of Chemistry: London, 2018.

[78] S. Costanzi, G. D. Koblenz, "Controlling Novichoks after Salisbury: revising the Chemical Weapons Convention schedules." *The Nonproliferation Review*, 2019, 26 (5-6), pp. 599-612. DOI: 10.1080/10736700.2019.1662618.

[79] L. Howes, "New nerve agents added to Chemical Weapons Convention Novichok and carbamate compounds are the first added to the treaty since it came into force." *Chem. Eng. News* 2 December 2019; <https://cen.acs.org/policy/chemical-weapons/New-nerve-agents-added-Chemical-Weapons-Convention/97/web/2019/12>

[80] M. Peplow. "Nerve agent attack on spy used 'Novichok' poison Chemical weapon used in U.K. assassination attempt was developed by Soviet Union during Cold War" *Chem. Eng. News* 2018, 96(12); <https://cen.acs.org/articles/96/i12/Nerve-agent-attack-on-spy-used-Novichok-poison.html>

[81] *Report of the Scientific Advisory Board's Workshop on Chemical Warfare Agent Toxicity, Emergency Response and Medical Countermeasures*, SAB-24/WP.2, 14 October 2016, The Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands;
www.opcw.org/sites/default/files/documents/SAB/en/sab-24-wp02_e_.pdf

[82] K Nixdorff. "Advances in the Targeted Delivery of Biochemical Agents," pp. 259-292 In *Preventing Chemical Weapons: Arms Control and Disarmament as the Sciences Converge*; M. Crowley, M. Dando, L. Shang (Eds.); Royal Society of Chemistry: London, 2018.

[83] Y. Min, J. M. Caster, M. J. Eblan, A. Z. Wang. "Clinical Translation of Nanomedicine." *Chem. Rev.* 2015, 115(19), pp. 11147-11190. DOI: 10.1021/acs.chemrev.5b00116.

[84] Adopted from J. E. Forman, C. M. Timperley. "Chemical Disarmament in a Technologically Evolving World." In *Responsible Conduct in Chemistry Research and Practice: Global Perspectives*; E. T. Contis, A. Campbell, D. Phillips, D., B. Miller, L. Brown (Eds.); ACS Symposium Series; American Chemical Society: Washington, DC, 2018; Vol. 1288, pp. 3- 35.

- [85] R. J. Mathews. "Central Nervous System-Acting Chemicals and the Chemical Weapons Convention: A Former Scientific Adviser's Perspective." *Pure Appl. Chem.* 2018, 90(10), pp. 1559-1675. DOI: 10.1515/pac-2018-0502.
- [86] S. Jeffery. "The Moscow theatre siege A chronology of events following the storming of a Russian theatre by a gang of heavily armed Chechen militants". *The Guardian*, 28 October 2002; <https://www.theguardian.com/world/2002/oct/28/chechnya.russia6>
- [87] *Central Nervous System Acting Chemicals - Considerations from the OPCW Scientific Advisory Board*, 28 November 2017; www.opcw.org/sites/default/files/documents/SAB/en/SAB_Considerations_on_CNS-Acting_Chemicals_2003-2017.pdf.
- [88] See for example: (a) Joint Paper: *Aerosolisation of Central Nervous System-Acting Chemicals for Law Enforcement Purposes*. RC-4/NAT.26, 30 November 2018, The Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/2018/11/rc4nat26%28e%29.pdf. (b) Russian Federation: *Aerosolisation of Chemical Nervous System-Acting Chemicals for Law Enforcement Purposes*, RC-4/NAT.9, 21 November 2018, The Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/2018/11/rc4nat09%28e%29.pdf.
- [89] Decision on aerosolised use of Central Nervous System-acting chemicals adopted by OPCW Conference of States Parties, Organization for the Prohibition of Chemical Weapons, 1 December 2021; www.opcw.org/media-centre/news/2021/12/decision-aerosolised-use-central-nervous-system-acting-chemicals-adopted.
- [90] The summary of the voting is available in Report of the Twenty-Sixth Session of the Conference of the States Parties, C-26/5, Organization for the Prohibition of Chemical Weapons, The Hague, 2021; www.opcw.org/sites/default/files/documents/2021/12/c2605%28e%29.pdf.
- [91] M. Crowley, M. Dando. Central Nervous System Weapons Dealt a Blow. *Science* 2022, 375 (6577), 153-154. DOI: 10.1126/science.abn6132.
- [92] Russian Federation: *Understanding Regarding the Aerosolized Use of Central Nervous System-Acting Chemicals for Law Enforcement Purposes*, EC-93/NAT.6, 6 March 2020, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/2020/03/ec93nat06%28e%29.pdf
- [93] People's Republic of China: Statement by the Delegation of the People's Republic of China to the OPCW at the Ninety-Fifth Session of the Executive Council, EC-95/NAT.30, 6 October 2020, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/2020/11/ec95nat30%28e%29.pdf
- [94] 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, 30 April 2020, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/CSP/RC-4/en/rc4dg01_e_.pdf
- [95] See for example *Chemical Munitions: Cost Estimates for Demilitarization and Production*, U.S. Government Accountability Office, NSIAD-86-1FS: 1985; <https://www.gao.gov/products/128358>

- [96] A. Mullard A. "The drug-maker's guide to the galaxy." *Nature* 2017, 549(7673), pp. 445-447. DOI: 10.1038/549445a.
- [97] See for example: P. S. Gromski, A. B. Henson, J. M. Granda, L. Cronin. "How to explore chemical space using algorithms and automation." *Nat Rev Chem* 2019, 3, pp. 119-128. DOI: 10.1038/s41570-018-0066-y.
- [98] C. M. Timperley, J. E. Forman, M. Abdollahi, A.S. Al-Amri, A. Baulig, D. Benachour, V. Borrett, F. A. Cariño, M. Geist, D. Gonzalez, W. Kane, Z. Kovarik, R. Martínez-Álvarez, N. M. Fusaro Mourão, S. Neffe, S. K. Raza, V. Rubaylo, A. G. Suárez, K. Takeuchi, C. Tang, F. Trifirò, F. Mauritz van Straten, P. S. Vanninen, S. Vučinić, V. Zaitsev, M. Zafar-Uz-Zaman, M. Saïd Zina, S. Holen. "Advice on assistance and protection provided by the Scientific Advisory Board of the Organisation for the Prohibition of Chemical Weapons: Part 1. On medical care and treatment of injuries from nerve agents." *Toxicology* 2019, 415, pp. 56-59. DOI: 10.1016/j.tox.2019.01.004.
- [99] C. M. Timperley, M. Abdollahi, A.S. Al-Amri, A. Baulig, D. Benachour, V. Borrett, F. A. Cariño, M. Geist, D. Gonzalez, W. Kane, Z. Kovarik, R. Martínez-Álvarez, N. M. Fusaro Mourão, S. Neffe, S. K. Raza, V. Rubaylo, A. G. Suárez, K. Takeuchi, C. Tang, F. Trifirò, F. Mauritz van Straten, P. S. Vanninen, S. Vučinić, V. Zaitsev, M. Zafar-Uz-Zaman, M. Saïd Zina, S. Holen, J. E. Forman, V. Suri. "Advice on Assistance and Protection from the Scientific Advisory Board of the Organisation for the Prohibition of Chemical Weapons: Part 2. On Preventing and Treating Health Effects from Acute, Prolonged, and Repeated Nerve Agent Exposure, and the Identification of Medical Countermeasures able to Reduce or Eliminate the Longer Term Health Effects of Nerve Agents." *Toxicology*, 2019, 413, pp. 13-23. DOI: 10.1016/j.tox.2018.11.009.
- [100] Designated Laboratories; www.opcw.org/designated-laboratories. For a current list of Designated Laboratories, see (a) *Note by the Director-General: Status of Laboratories Designated for the Analysis of Authentic Environmental Samples*, S/1893/2020, 2 September 2020, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/2020/09/s-1893-2020%28e%29%20%281%29.pdf. (b) *Note by the Technical Secretariat: Status of Laboratories Designated for the Analysis of Authentic Biomedical Samples*, S/1904/2020, 2 October 2020, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/2020/10/s-1904-2020%28e%29.pdf
- [101] *Recommended Operating Procedures for Analysis in the Verification of Chemical Disarmament 2017 Edition*. P. Vanninen, (Ed.), University of Helsinki: Helsinki, Finland, 2017.
- [102] 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. "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." *Talanta* 2018, 188, pp. 808-832. DOI: 10.1016/j.talanta.2018.04.022.
- [103] See for example S. Mogl, P. Siegenthaler, B. Schmidt. "Chemical weapons in the Syrian conflict." *Spiez Laboratory Annual report 2013*; 2013; pp. 26 - 33;
https://www.labor-spiez.ch/pdf/en/dok/jab/88_003_e_laborspiez_jahresbericht_2013_web.pdf

[104] The Japanese National Research Institute of Police Science participated in a recent OPCW Proficiency Test, see: *Note by the Director-General: Evaluation of the Results of the Fifth Official OPCW Biomedical Proficiency Test*, S/1903/2020, 2 October 2020, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands;
www.opcw.org/sites/default/files/documents/2020/10/s-1903-2020%28e%29.pdf

[105] See for example paragraphs 12.1 to 12.2 of *Summary of the Third Meeting of the Scientific Advisory Board Temporary Working Group on Investigative Science and Technology*, SAB-28/WP.3, 4 June 2019, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands;
www.opcw.org/sites/default/files/documents/2019/06/sab-28-wp03%28e%29.pdf

[106] *Report of the Scientific Advisory Board's Workshop on Trends in Chemical Production*, SAB-26/WP.2, 19 October 2017, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/SAB/en/sab-26-wp02_e_.pdf

[107] *FACTS & FIGURES of the European chemical industry*, cefic; <https://cefic.org/a-pillar-of-the-european-economy/>.

[108] P. Heney. 2021 Global R&D Funding Forecast released. R&D World, 2021;
<https://www.rdworldonline.com/2021-global-rd-funding-forecast-released/>.

[109] *2022 National Science Board Science and Engineering Indicators: The State of U.S. Science and Engineering*. National Science Foundation, National Science Board, and National Center for Science and Engineering Statistics, Alexandria, VA, USA; <https://nces.nsf.gov/pubs/nsb20221>. .

[110] *Measures to Prevent Hostile Use of Toxic Chemicals by Non-State Actors*, S/1291/2015, OPCW, The Hague, 26 June 2015;
www.opcw.org/sites/default/files/documents/S_series/2015/en/s-1291-2015_e_.pdf.

[111] Chlorine, Royal Society of Chemistry, Periodic Table; <https://www.rsc.org/periodic-table/element/17/chlorine>.

[112] (a) See paragraphs 9.17 to 9.18 of *Report of the Twenty-Fifth Session of the Scientific Advisory Board*, SAB-25/1*, 31 March 2017, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands; www.opcw.org/sites/default/files/documents/SAB/en/sab2501_e_.pdf. (b) *Note by the Technical*

Secretariat: Report of the OPCW Fact-Finding Mission in Syria Regarding Alleged Incidents in Marea,

Syrian Arab Republic, August 2015, S/1320/2015, 29 October 2015, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands;
www.opcw.org/sites/default/files/documents/2018/11/s-1320-2015_e_.pdf.

[113] O. Björnham, H. Grahn, P. von Schoenberg, B. Liljedahl, A. Waleij, N. Brännström. "The 2016 Al-Mishraq sulphur plant fire: Source and health risk area estimation." *Atmos. Environ.* 2017, 169, pp. 287-296.

[114] D. Russell, J. Simpson. "Emergency planning and preparedness for the deliberate release of toxic industrial chemicals," *Clinical Toxicology*, 2010, 48(3), pp. 171-176. DOI: 10.3109/15563651003698042.

[115] (a) *Investigative Science and Technology: Report of the Scientific Advisory Board's Temporary*

Working Group, SAB/REP/1/19, 1 December 2019, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands;
www.opcw.org/sites/default/files/documents/2020/11/TWG%20Investigative%20Science%20Final%20Report%20-%20January%202020%20%281%29.pdf. (b) J. E. Forman, P. Aas, M. Abdollahi, I. P. Alonso, A. Baulig, R. Becker-Arnold, V. Borrett, F. A. Cariño, C. Curty, D. Gonzalez, Z. Kovarik, R. Martínez-Álvarez, R. Mikulak, E. de Souza Nogueira, P. Ramasami, S. K. Raza, A. E. M. Saeed, K. Takeuchi, C. Tang, F. Trifirò, F. M. van Straten, F. Waqar, V. Zaitsev, M. Saïd Zina, K. Grolmusová, G. Valente, M. Payva, S. Sun, A. Yang, D. van Eerten. “Innovative Technologies for Chemical Security,” *Pure Appl. Chem.* 2018, 90(10), 1527-1557. DOI: 10.1515/pac-2018-0908. (c) *Verification Report of the Scientific Advisory Board’s Temporary Working Group*, SAB/REP/1/15, 11 June 2015, Organisation for the Prohibition of Chemical Weapons, The Hague, The Netherlands;
www.opcw.org/sites/default/files/documents/SAB/en/Final_Report_of_SAB_TWG_on_Verification_-_as_presented_to_SAB.pdf

[116] See Ralf Trapp, *Lessons Learned from the OPCW Mission in Syria*, Report submitted to the Director-General of the Technical Secretariat of the OPCW, 16 December 2015;
<http://www.the-trench.org/wp-content/uploads/2016/01/Trapp-20151216-OPCW-Syria-lessons-learned.pdf>

[117] S. Mullins. “Terrorism in the Indo-Pacific: The Year Gone By and the Road Ahead.” *Journal of Indo-Pacific Affairs*, Summer 2020, 4-35; <https://media.defense.gov/2020/Jun/08/2002311969/-1/-1/1/MULLINS.PDF>

[118] C. Santos, T. El Zahran, J. Weiland, M. Anwar, J. Schier. Characterizing chemical terrorism incidents collected by the Global Terrorism Database, 1970-2015. *Prehosp Disaster Med.* 2019, 34(4), 385-392.

[119] M. Court, B. Edwards, F. Issa, A. Voskanyan, G. Ciottone. “Counter-Terrorism Medicine: Creating a Medical Initiative Mandated by Escalating Asymmetric Attacks.” *Prehospital and Disaster Medicine* 2020, pp. 1-4. DOI: 10.1017/S1049023X2000103X.

[120] The United States Chemical Facility Anti-Terrorism Standards (CFATS) provides insights into security concerns related to chemical infrastructure; <https://www.cisa.gov/chemical-facility-anti-terrorism-standards>.

[121] Australia Group Export Controlled Chemical Weapons Precursors, available at: <https://www.dfat.gov.au/publications/minisite/theaustraliagroupnet/site/en/precursors.html>

[122] The Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies Control Lists, available at: <https://www.wassenaar.org/control-lists/>

IV. NAUTILUS INVITES YOUR RESPONSE

The Nautilus Asia Peace and Security Network invites your responses to this report. Please send responses to: nautilus@nautilus.org. Responses will be considered for redistribution to the network only if they include the author’s name, affiliation, and explicit consent

View this online at: <https://nautilus.org/napsnet/napsnet-special-reports/chemical-weapons-i-the-asia-pacific-history-science-and-future-prospect/>

Nautilus Institute

608 San Miguel Ave., Berkeley, CA 94707-1535 | Phone: (510) 423-0372 | Email:

nautilus@nautilus.org