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President's Message
THE VALUE OF SCIENTIFIC ANALYSIS

A PRIMER ON TOXIC CHEMICALS

INVESTIGATING CHEMICAL ATTACKS USING SOCIAL MEDIA

Case Study
CHEMICAL ATTACK IN JEBEL MARRA

and more ***inside.***

Guided-missile destroyer USS Porter conducting strike operations against Shayrat airbase in western Syria on April 7, 2017. President Trump authorized the strike following the chemical attack on Khan Shaykhun, Syria — suspected to have been conducted by the Syrian government — on April 4, 2017.

Photo/Kyle Soard, Defense Imagery Distribution System

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Letter to the Editor

Response to "Counting the Uncountable Deaths of Chernobyl"

Alexander DeVolpi
Retired, Argonne National Laboratory

The winter *PIR* article, "Calculating the Uncountable Deaths from Chernobyl,"[1] is self-contradictory: Inasmuch as the alleged deaths are "uncountable," the conspicuous conclusion is that – aside from initial reactor-operator casualties – no one else died because of radiation! The article contains page after page of never-validated, ill-advised, distractive thinking.

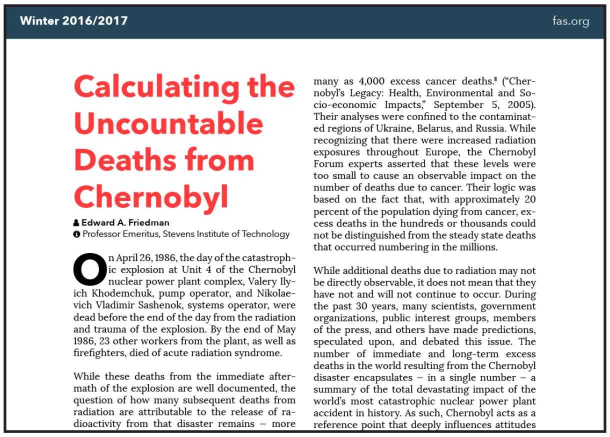
Nobody from the general public has been brought to a morgue as a result of radiation from the accident. Nevertheless, the author creates "alternative" facts, estimating (which means guessing) 20,000 fatalities attributed to Chernobyl radiation.

It's pathetic. Thousands and thousands of words, not an actual dead body. The real tragedy is in Dr. Friedman thinking that his article will sway more than the gullible. After 30 years, some theorists find it insufferable that they're still unable to identify specific radiation-induced casualties among the public; so they invent hypotheses and get them printed in unwary or unreviewed publications. Indeed, because of the accident, there have been increased levels of stress, depression, alcoholism, and drug abuse: What would you expect after being bombarded by the theories of so-called scientists?

What Dr. Friedman assumes, with great fanfare, in baseless calculations is the linear no-threshold (LNT) model. Despite high-falutin endorsers, there's no solid evidence of linearity in low-level radiation effects; Dr. Friedman's fatality estimate is based on hoary theory, not on bodies found in the morgue (because there have been none). Published, never-materialized estimates of deaths from Chernobyl have ranged from a "mere" 26,000 to nearly a ridiculous million – but not one carcass in the morgue providing confirmatory post-mortem validation.

Dr. Friedman would be better off consulting and appreciating a broader range of technical literature,[2] including assessments by Jerry Cuttler.[3] Not once did Dr. Friedman cite any of the thorough international post-accident assessments by the United Nations, IAEA, Chernobyl Forum, or World Health Organization.

Having often been an outsider, I sympathize with those who challenge established posture. Not tied to any institution or conflict of interest, I'm simply reiterating that after 30 years, there's no evidence any member of the public died because of Chernobyl radiation.


Winter 2016/2017 fas.org

Calculating the Uncountable Deaths from Chernobyl

Edward A. Friedman
Professor Emeritus, Stevens Institute of Technology

On April 26, 1986, the day of the catastrophic explosion at Unit 4 of the Chernobyl nuclear power plant complex, Valery Ilyich Khodemchuk, pump operator, and Nikolaevich Vladimir Sashenok, systems operator, were dead before the end of the day from the radiation and trauma of the explosion. By the end of May 1986, 23 other workers from the plant, as well as firefighters, died of acute radiation syndrome.

While these deaths from the immediate aftermath of the explosion are well documented, the question of how many subsequent deaths from radiation are attributable to the release of radioactivity from that disaster remains – more many as 4,000 excess cancer deaths. ("Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts," September 5, 2005). Their analyses were confined to the contaminated regions of Ukraine, Belarus, and Russia. While recognizing that there were increased radiation exposures throughout Europe, the Chernobyl Forum experts asserted that these levels were too small to cause an observable impact on the number of deaths due to cancer. Their logic was based on the fact that, with approximately 20 percent of the population dying from cancer, excess deaths in the hundreds or thousands could not be distinguished from the steady state deaths that occurred numbering in the millions.

While additional deaths due to radiation may not be directly observable, it does not mean that they have not and will not continue to occur. During the past 30 years, many scientists, government organizations, public interest groups, members of the press, and others have made predictions, speculated upon, and debated this issue. The number of immediate and long-term excess deaths in the world resulting from the Chernobyl disaster encapsulates – in a single number – a summary of the total devastating impact of the world's most catastrophic nuclear power plant accident in history. As such, Chernobyl acts as a reference point that deeply influences attitudes

An excerpt from Dr. Friedman's piece as it appears in the last *Public Interest Report* (Vol. 69, No. 3).

1 Edward A. Friedman, "Calculating the Uncountable Deaths from Chernobyl," *Public Interest Report* 69, no. 3 (2016), https://issuu.com/fascientists/docs/pir-2016_v3.1.

2 Alexander DeVolpi, *Nuclear Insights: The Cold War Legacy. Volume 2: Nuclear Threats and Prospects (A Knowledgeable Assessment)* (DeVolpi, Inc., 2011), Kindle.

3 Jerry M. Cuttler, "Urgent Change Needed to Radiation Protection Policy," *Health Physics* 110, no. 3 (March 2016).

Letter to the Editor

Response to Dr. Alexander DeVolpi's Letter to the Editor

Edward A. Friedman
Professor Emeritus, Stevens Institute of Technology

Alexander DeVolpi in his commentary about my essay, "Calculating the Uncountable Deaths of Chernobyl" sees the title as self-contradictory. To some, that may be the message, but others might see it as an expression of irony, as well as an acknowledgement that the world was not littered with corpses labelled, "Dead from Chernobyl Disaster Radiation."

While Dr. DeVolpi asserts that I did not "once" cite "any of the thorough international post-assessments by the United Nations, IAEA, Chernobyl Forum, or the World Health Organization" he seems to have missed my opening statement:[1]

> A team of more than 100 experts assembled by eight UN-related agencies, known as the Chernobyl Forum, asserted in 2005 that long term consequences of Chernobyl could result in as many as 4,000 excess cancer deaths. (Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts, September 5, 2005). Their analyses were confined to the contaminated regions of Ukraine, Belarus, and Russia. While recognizing that there were increased radiation exposures throughout Europe, the Chernobyl Forum experts asserted that these levels were too small to cause an observable impact on the number of deaths due to cancer. Their logic was based on the fact that, with approximately 20 percent of the population dying from cancer, excess deaths in the hundreds or thousands could not be distinguished from the steady state deaths that occurred numbering in the millions.

Most of the 4,000 deaths cited by these international UN related agencies are based upon calculations of man-Sieverts times the probability of death due to radiation-induced fatal cancer per man-Sievert of about 5 percent. The methodology that I found meaningful in my essay is exactly that employed by the United Nations, IAEA, Chernobyl Forum, and World Health Organization that Dr. DeVolpi holds up as paragons of scientific correctness. The exception being that I assert that those organizations failed to include geographic regions where significant radiation from Chernobyl was manifest.

My analysis disputes the assertion by the Chernobyl Forum that the impact of radiation outside of Ukraine, Belarus, and Russia can be ignored by showing that high levels of radiation, directly attributable to Chernobyl, were found in sheep and reindeer of northern Europe at distances of up to 1,500 miles from Chernobyl. Using data from the United Nations Scientific Committee on the Effects of Radiation (UNSCEAR) 2008,[2] I noted that there were significant figures reported at distances in the 1,500-mile range in northern and southern Europe, Turkey, the Middle East, and even northern Africa.[3]

UNSCEAR 1988 and UNSCEAR 2008 reports show clearly that plumes with radioactive fallout travelled effectively in all directions from Chernobyl. Istanbul is 657 air miles from Kiev and Cairo is 1,400 air miles. Even if one were to exclude all regions of the world that are more remote, the total number of deaths would only be 2,000 less than those calculated by Lizbeth Gronlund and quoted in my essay.

Dr. DeVolpi also states: "What Dr. Friedman assumes, with great fanfare, in baseless calculations is the LNT model." Far from being baseless, research during the past decade increasingly supports the

1 Edward A. Friedman, "Calculating the Uncountable Deaths from Chernobyl," *Public Interest Report* 69, no. 3 (2016), https://issuu.com/fascientists/docs/pir-2016_v3.1.

2 "Sources and Effects of Ionizing Radiation," United Nations Scientific Committee on the Effects of Atomic Radiation, *Report to the General Assembly with Scientific Annexes* I (2008), 32, http://www.unscear.org/docs/publications/2008/UNSCEAR_2008_Annex-A-CORR.pdf.

3 "Calculating the Uncountable Deaths from Chernobyl."

linear no-threshold (LNT) model. My essay cites the extremely compelling study done in recent years by Richardson et al.[4] The following is an extract from my essay:[5]

> In the Bier VII – Phase 2 report it states (on page 290):
>
> > … the most promising studies for the direct assessment of risk at low doses and low dose rates are those of nuclear workers who have been monitored for radiation exposure through the use of personal dosimeters.
>
> While there have been a number of such studies, a definitive report was published on September 9, 2015 by a team of researchers from the United States and Europe, with Professor David B. Richardson of the University of North Carolina as the lead author. In this cohort study, 308,297 workers in the nuclear industry from France, the United Kingdom, and the United States detailed monitoring data for external exposure to ionizing radiation were linked to death certificate data. This data was acquired through 1968-2004 in France, 1946-2001 in the United Kingdom, and 1944-2005 in the United States. The report notes:
>
> > Follow-up encompassed 8.2 million person years. Of 66,632 known deaths by the end of the follow-up 17,957 excess solid cancer deaths were attributed to radiation.

I should add that it is inappropriate for Dr. DeVolpi to disparage rigorous scientific studies which, in fields as disparate as quantum mechanics and genetics, utilize probabilistic analysis.

4 David B. Richardson, et al., "Risk of Cancer from occupational exposure to ionizing radiation retrospective cohort study of workers in France, the United Kingdom, and the United States (INWORKS)," BMJ 2015, no. 351 (October 20, 2015), http://bmj.com/content/351/bmj.h5359.

5 "Calculating the Uncountable Deaths from Chernobyl."

President's Message

The Value of Scientific Analysis – Chemical Weapons Attacks

Charles D. Ferguson
President, Federation of American Scientists

On April 4, 2017, at least 89 people were killed in a chemical attack on the rebel-held town of Khan Shaykhun in northwestern Syria, including at least 33 children.[1] On April 19, the Organisation for the Prevention of Chemical Weapons (OPCW) determined that victims of the chemical attack were exposed to sarin,[2] a nerve agent that inhibits the proper regulation of gland and muscle stimulation, leading to constant stimulation and to potentially fatal respiratory failure.[3]

In the aftermath of the Khan Shaykhun chemical attack, who carried out the attack was the central question in the global political landscape. While the United States is confident that the Syrian government executed the attack against its own people,[4] Syrian President Bashar al-Assad stated that "the West, mainly the United States ... fabricated the whole story in order to have a pretext for the [U.S. retaliatory] attack."[5] Likewise, Russia's Ministry of Defence stated that the Syrian government did carry out the chemical attack, but its target was a "large terrorist ammunition depot" on the "outskirts" of Khan Shaykhun.[6]

The United States has refuted both statements by Syria and Russia, stating: "The Syrian regime and its primary backer, Russia, have sought to confuse the world community about who is responsible for [the chemical attack on Khan Shaykhun] and earlier attacks."[7] Two days after the chemical attack, on April 6, President Donald J. Trump ordered a military strike against the Syrian government with 59 Tomahawk Missiles targeting the Shayrat air base in western Syria.[8]

The last major chemical attacks that occurred before the assembly of this *Public Interest Report* (PIR) were the series of at least eight documented chlorine gas attacks by the Syrian government on rebel-controlled areas in Aleppo (from November 17 to December 13, 2016).[9] Though the circumstances leading to the heightened rele-

1 "Report No. 4 on Khan Shaikhoon Attack," Syria: Idlib Health Directorate and Syria Civil Defence, April 7, 2017. Accessed April 26, 2017. https://twitter.com/SyriaCivilDef/status/850323422894850048.

2 "OPCW Director-General Shares Inctrovertrible Laboratory Results Concluding Exposure to Sarin," Organisation for the Prohibition of Chemical Weapons, April 19, 2017. Accessed April 26, 2017. https://www.opcw.org/news/article/opcw-director-general-shares-incontrovertible-laboratory-results-concluding-exposure-to-sarin.

3 "Facts About Sarin," Center for Disease Control and Prevention, November 18, 2015. Accessed April 26, 2017. https://emergency.cdc.gov/agent/sarin/basics/facts.asp.

4 "Declassified U.S. Report on Chemical Weapons," The New York Times, April 11, 2017. Accessed April 26, 2017. https://www.nytimes.com/interactive/2017/04/11/world/middleeast/document-Syria-Chemical-Weapons-Report-White-House.html?_r=0.

5 Sammy Ketz and Rana Moussaoui, "Syria's Assad says chemical attack '100 percent fabrication,'" AFP (via Yahoo! News), April 13, 2017. Accessed April 26, 2017. https://www.yahoo.com/news/syrias-assad-says-chemical-attack-100-percent-fabrication-135550600.html.

6 "Syria chemical 'attack': What we know," BBC News, April 26, 2017. Accessed April 26, 2017. http://www.bbc.com/news/world-middle-east-39500947.

7 "Declassified U.S. Report on Chemical Weapons."

8 "Statement by President Trump on Syria," The White House, April 6, 2017. Accessed April 26, 2017. https://www.whitehouse.gov/the-press-office/2017/04/06/statement-president-trump-syria.

9 "Syria: Coordinated Chemical Attacks," Human Rights Watch, February 13, 2017. Accessed April 26, 2017. https://

vance of this *PIR* are abhorrent – just less than 30 days removed from the chemical attack on Khan Shaykhun – it is the mission of the pieces collected in this issue to illuminate in greater detail the processes and techniques implemented for investigating chemical attacks, and what these attacks mean for the security of the United States and nations abroad.

Dr. George R. Famini (Director, Retired, DHS Chemical Security Analysis Center) provides a succinct overview of the history of chemical weapons, especially as it pertains to U.S. national security, including chemical taxonomies, toxidrome descriptions, and a chronology of World War I era chemical weapons.

Ole Solvang (Deputy Director, Emergencies), Peter Bouckaert (Director, Emergencies), and Nadim Houry (Director, Terrorism and Counterterrorism Program) of Human Rights Watch (HRW) delve into the processes and techniques HRW implements in its investigations. Specifically, Solvang et al. provide a detailed analysis of HRW's investigation of the 2013 chemical attacks in Ghouta, Syria.

Finally, Dr. Jennifer S. Knaack (Mercer University, College of Pharmacy), Dr. Keith Ward (George Mason University, School of Systems Biology), and Jonathan Loeb (Senior Crisis Advisor, Amnesty International) synthesize the themes and information established by the aforementioned *PIR* contributors with a comprehensive case study analysis of the symptoms and potential chemical weapons use in Jebel Marra, a remote region in Darfur, Sudan.

I hope readers of this *Public Interest Report* will learn from the sound and thorough dissection of the investigatory processes applied to verifying chemical attacks and identifying the chemicals and agents used in such attacks. On behalf of the Federation of American Scientists, I am grateful for your interest in these issues and your support of FAS.

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www.hrw.org/news/2017/02/13/syria-coordinated-chemical-attacks-aleppo.

Threat of Toxic Chemicals to the American Homeland

George R. Famini
Director (Ret.), DHS Chemical Security Analysis Center

Toxic chemicals have been a major component of human civilization for many years. Uses in manufacture, medicine, pest control, etc., have made such materials both commonplace and readily available. They are an integral part of society and have been used to develop products that have vastly improved the quality of life, from better clothing to improved agriculture. According to the American Chemical Society, there are over 60 million chemicals registered worldwide. Of these, it is estimated that about 85,000 are used in commerce. Though not all of these could be considered toxic, even if 10% are as or more toxic than ammonia (a common benchmark), then there are nearly 10,000 chemicals that can elicit toxic lethal effects in routine commerce today.[1]

Furthermore, many of the very toxic chemicals are found routinely in the home and are sold in quantity locally, from bleaches (sodium hypochlorite) and acid cleaners (muriatic acid) to pesticides (organophosphorus-, carbamate-, and phosphide-based). Several of these household chemicals have also been used in a growing epidemic of "chemical suicides," where binary-based mixtures are combined rapidly to produce lethal levels of toxic gases. Common gases produced in chemical suicides include hydrogen sulfide (using lime sulfur and muriatic acid), phosphine (using aluminum phosphide and water), and hydrogen cyanide (using sodium cyanide and muriatic acid).[2]

It is not surprising, therefore, that some of these toxic chemicals have been considered and used frequently in warfare and armed conflicts, or have spawned the synthesis of even more toxic chemicals.[3] One may argue that toxic chemical use, i.e. chemical warfare, may not have been overly successful in military conflicts against prepared soldiers. However, use against unprotected civilian populations can be effective, and there is no doubt that the use of toxic chemicals has generated tremendous fear.

Common toxic chemicals typically have lethality levels 10-100 times less than the classical chemical warfare agents.[4] Looking at consequences/impact alone, however, is not sufficient to understand and assess the real risk associated with a given chemical or class of chemicals. This is because risk incorporates other facets than just toxicity or consequences. There are many different definitions of risk depending on specific application or perception. For our purposes here, we will consider risk as defined in probabilistic risk analysis (PRA), where the risk is a function of the likelihood of an event and the impact associated with that event.[5] This is relevant when looking at the range of toxic chemicals, as many (such as the classical chemical warfare agents) will have greater impacts, but have much lower likelihoods.

Analogously, commercially available toxic chemicals will be typically less toxic but will generally be readily available for purchase. Two of the commonly used documents in assessing the risk associated with toxic industrial release, the International Task Force-25 (ITF-25) and the International Task Force-40 (ITF-40), apply different approaches in assessing the risk using the general

1 "CAS REGISTRY and CAS Registry Number FAQs," CAS, n.d., Accessed May 1, 2017. http://www.cas.org/content/chemical-substances/faqs.

2 R. G. Bogle, et al., "Aluminium phosphide poisoning," *Emergency Medical Journal* 23, no. 1 (2006): 23 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2564148.

3 E. M. Cowell, "Chemical Warfare and the Doctor–I," *The British Medical Journal* 2 (1939): 736–738. https://dx.doi.org/10.1136%2Fbmj.2.4109.736.

4 George Famini and S. Chesler, "(U) Chemical Threat Materials Fact Book," U.S. Department of Homeland Security, Science and Technology Directorate, Chemical Analysis Security Center, 2009.

5 R. M. Cooke and T. J. Bedford, *Probabilistic Risk Analysis: Foundations and Methods* (London: Cambridge University Press, 2001). Print.

PRA methodology of considering both likelihood and impact. In ITF-25, the likelihood was determined based primarily on the number of continents where the material was produced, and the impact was a combination of the physical state (gas versus liquid; solids were excluded) and toxicity.[6] ITF-40 used a classical risk management table approach and multiple measures to define both the likelihood and the impact.[7]

While the focus of this article is on commercially available toxic industrial chemicals (TICs), including pesticides and some pharmaceuticals, because of the integral nature of these materials in chemical warfare and how common TICs have led to the super toxic chemical warfare agents of today, it is necessary to include some discussion of chemical warfare.

Although the intentional use of chemical agents, especially chemicals commonly thought of as toxic industrial chemicals, dates back centuries, the real modern beginning can be traced to World War I (WWI), in which a number of commonly available chemicals were first used on the battlefield. While today, chlorine and sulfur mustard (bis-2-chloroethyl sulfide) are most commonly remembered as being used, 20 separate chemicals have been documented as having been used as toxic chemical warfare agents.[8] Table 1 lists those chemicals, as well as the date of their original use.[9]

Name	First Use
Xylyl bromide	1914
Chlorine	1915
Phosgene	1915
Benzyl bromide	1915
Chloromethyl chloroformate	1915
Trichloromethyl chloroformate	1916
Chloropicrin	1916
Stannic chloride	1916
Ethyl iodoacetate	1916
Bromoacetone	1916
Monobromomethyl ethyl ketone	1916
Acrolein	1916
Hydrogen cyanide (Prussic acid)	1916
Hydrogen sulfid (Sulphuretted hydrogen)	1916
Diphenylchloroarsine (Diphenyl chlorasine)	1917
α-chlorotoluene (Benzyl chloride)	1917
Mustard gas (Bis(2-chloroethyl) sulfide)	1917
Bis(chloromethyl) ether (Dichloromethyl ether)	1918
Ethyldichloroarsine	1918
N-Ethylcarbazole 679	1918

Table 1: Toxic chemicals used in World War I.

Upon inspection, all of these chemicals are commonly available industrial chemicals (with one exception). Sulfur mustard was the only lethally toxic chemical developed in WWI specifically for use as a chemical warfare agent. In addition, three non-lethal organoarsenic compounds termed vomiting agents (for obvious reasons) were developed by chemists during WWI: diphenylchloroarsine (DA), diphenylcyanoarsine (DC), and diphenylaminearsine (DM). Of the three, DM, also called adamsite, was considered the most effective and was further used. DM was also considered for use after WWI as a riot control agent.

Of course, after World War I, several other chemical warfare agents (nerve agents, commonly referred to as the "G series" and "V series") were developed. It is interesting that both the G agents

6 A. K. Stuempfle, et al., "Hazard from Industrial Chemicals: United States, United Kingdom, Canada Memorandum of Understanding on Chemical and Biological Defense," International Task Force-25, 1996.

7 S. J. Armour, et al., "Industrial Chemicals - Operational and Medical Concerns: United States, United Kingdom, Canada Memorandum of Understanding on Chemical and Biological Defense," International Task Force-40, 2003.

8 Ibid.

9 "Chemical weapons in World War I," Wikipedia, April 24, 2017. Accessed May 2, 2017, https://en.wikipedia.org/wiki/Chemical_weapons_in_World_War_I#Gases_used.

and V agents were originally developed as a new series of pesticides. In fact, VG, or Amiton, was briefly marketed in the 1950s as an insecticide but was removed because of its toxicity. Also, many of the commonly used organophosphorus-based pesticides have chemical structures that are similar to either the G series or the V series agents (dicrotophos, cyanophenphos, malathion, and parathion, to name just a few). For a detailed discussion of the history of chemical warfare, the reader is directed to chapter two of *Medical Aspects of Chemical Warfare*.[10]

The original use of chemicals, both TICs and chemical warfare agents (CWAs), were developed for use on a battlefield. This meant that some of the chemicals originally considered were not employed because they were not toxic enough, dissipated too fast, or had other undesired characteristics. However, in today's environment where civilian venues may be selected, many different target types become possible. Enclosed venues, such as subway platforms or cars, office buildings, etc., provide an attractive release point for lower toxicity industrial gases because the indoor environment traps the gases and keeps them from being diluted. Furthermore, indoor environments make lighter-than-air gases like hydrogen cyanide or ammonia much more effective.

Toxic Chemicals: Wide Range of Chemicals

As mentioned above, an enormous number of toxic chemicals are commercially available. Developing individual countermeasures for every toxic chemical threat is prohibitive in terms of time and cost. Toxic chemicals, especially those that have significant non-chemical warfare use, present their toxic effects in a variety of ways using a variety of different mechanisms. In a collaborative effort with the American College of Medical Toxicologists (ACMT), the Department of Homeland Security's Chemical Security Analysis Center (CSAC) developed a series of toxidrome classes. Chemicals within a class present to medical professionals symptomatically in a similar way, which permits a wide range of potentially lethal chemicals, ranging across wide ranges of structural classes, to be categorized by a minimal number of similarly acting mechanisms.[11] Table 2 provides a list of the toxidrome classes used by CSAC, as well as a description of each of the toxidromes.

Toxidrome	Description
Anticoagulant	Alteration of blood coagulation that results in abnormal bleeding indicated by excessive bruising, and bleeding from mucous membranes, the stomach, intestines, urinary bladder, wounds, and other body sites such as intracranial and retroperitoneal.
Blood	Inability to use oxygen, leading to acute-onset gasping, convulsions, loss of consciousness, breathing cessation, and cardiac arrest.
Cholinergic (CWA)	Over stimulation of cholinergic receptors leading to first activation, and then fatigue of target organs, leading to pinpoint pupils (miosis), seizing, wheezing, twitching, and leaking all over.
Cholinergic (Other)	Over stimulation of cholinergic receptors leading to first activation, and then fatigue of target organs, leading to pinpoint pupils (miosis), seizing, wheezing, twitching, and leaking all over.
Convulsant	Central nervous system excitation (GABA antagonism and/or glutamate agonism and/or glycine antagonism) leading to generalized convulsions.
Encephalopathy	Primarily impacting on level of consciousness and global central nervous system (CNS) function, without prominent convulsions or impact on respiratory or cardiovascular systems.
Hemolytic/ Methemoglobinemia	Impaired oxygen delivery to cells based on disruption of red blood cell itself (hemolysis) or oxidation of hemoglobin (methemoglobinemia) leading to impaired oxygen carrying and releasing capacity.
Metabolic	Predominantly composed of inorganic metals/metalloids which act via interference with multiple receptors and/or intracellular processes, leading to multiple organ dysfunction. Many of these share early gastrointestinal symptoms, with subsequent hair, nail, kidney, and/or neurological abnormalities.

10 J. Smart, et al.; History of the Chemical Threat, Chemical Terrorism, and its Implications for Military Medicine," in *Medical Aspects of Chemical Warfare*, Office of the Surgeon General, United States Army, 2008.

11 Carol Brevett, et al., *Utility of Toxidromes for the Mitigation of Mass Casualty Events, In preparation.*

Toxidrome	Description
Opioid	Opioid agonism leading to pinpoint pupils (miosis), and central nervous system and respiratory depression.
Sympathomimetic/ Stimulant	Stress- or toxicant-induced catecholamine excess or central nervous system excitation leading to confusion, panic, and increased pulse, respiration, and blood pressure.
Irritant/Corrosive (to include upper/lower INH subdivisions)	INH: Immediate effects to the respiratory/pulmonary tract presenting as nasal and oral secretions, coughing, wheezing, and/or respiratory distress that may progress to rapid systemic toxicity.
	ING: Immediate effects to the oropharynx and gastrointestinal (GI) tract presenting as burns, drooling, nausea, vomiting, and diarrhea that may progress to rapid systemic toxicity.
	TOP: Immediate effects range from minor irritation to severe skin, eye, and mucosal membrane effects, which may progress to rapid systemic toxicity.
Vesicant	Same as irritant/corrosive.

Table 2: Toxidromes for common toxic chemical materials.

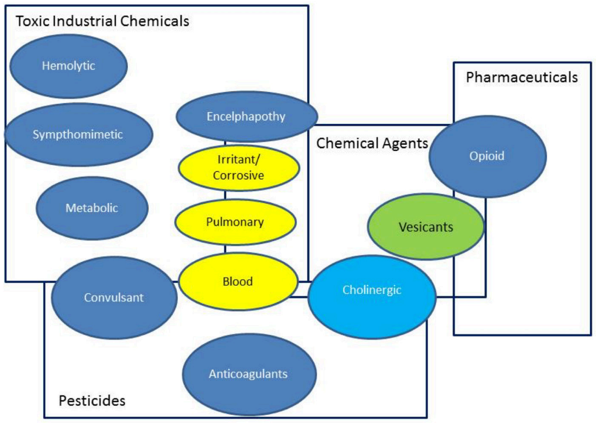

Figure 1: Chemical taxonomy.

Using this toxidrome classification as a basis, it is possible to categorize toxic chemicals that can be used intentionally in a kind of taxonomy, placing each toxidrome in one of multiple boxes, as shown in Figure 1 (toxic industrial chemicals, chemical warfare agents, pharmaceuticals, and pesticides). As can be seen, several of the toxidromes span multiple groups, including most of the commonly used TICs mentioned above, which were used as the first CWAs in WWI, notably in the pulmonary and blood categories. Examples include chlorine (a common disinfectant and precursor to many other materials), phosgene (a precursor for many pesticides and polymers), and acrolein (a precursor for acrylic acid-based products and polymers), to identify just a few.

Phosgene, a very common chemical with many industrial uses, accounted for over 80% of the fatalities caused by chemical attacks in WWI.[12] Other materials, such as sulfur mustard and chlorine, were used with greater frequency, but their lethal toxicity is much less, and they caused predominantly moderate and less severe injuries, which recent news stories in the Middle East verify as attacks with chlorine or mustard produce limited fatalities but large numbers of injuries.

In addition to commonly used toxic industrial chemicals, two other categories of chemicals that could be used as intentional lethal agents are pesticides and selected pharmaceuticals. The most lethal chemical warfare agents identified today (and subject to the Chemical Weapons Convention ban under the Organisation for the Prohibition of Chemical Warfare) include chemicals that were originally developed as pesticides, notably the G series agents and the V series agents.[13]

However, there are a number of other commonly available pesticides that could pose dangers to unprotected civilian populations. Today, most of the readily available pesticides, if used in sufficient quantities, can be toxic to unprotected populations. In 2012, an attack with parathion on a girls' school in Afghanistan killed or injured 160 students and teachers.[14] In addition to organophosphorus (OP) cholinergic chemicals, such as parathion, malathion, dicrotophos, and others, there are non-OP cholinergic chemicals that are lethally toxic and readily available. The most common class of the non-OP cholinergic chemicals is

12 P. Rega, "CBRNE - Lung-Damaging Agents, Phosgene," May 27, 2009. Accessed May 1, 2017, http://emedicine.medscape.com.

13 "Summary of CWC-Schedules and their Relevance to Chemical Warfare", National Authority for the Chemical Weapons Convention (Australia). Retrieved October 7, 2006, PDF.

14 Masoud Popalzai, "Official: 160 girls poisoned at Afghan school," CNN, May 29, 2012. Accessed May 1, 2017, http://www.cnn.com/2012/05/29/world/asia/afghanistan-girls-poisoned.

the carbamates,[15] common examples being aldicarb, lavin, and carbaryl.[16]

In addition to anticholinergic pesticides, two other relevant toxidromes involving pesticides are convulsants and anticoagulants. A classic example of a convulsant pesticide used in an intentional event is tetramethylenedisulfotetramine (TETS), which has been used several times over the past 20 years in China and, though banned in most countries, it is both readily available and easily synthesized. In separately reported incidents, 100 people have been killed due to food poisoned using TETS.[17, 18] In addition, there are numerous anecdotal stories of accidental poisoning deaths and injuries when TETS, placed in bait traps as a rodenticide, was ingested. Other pesticides that fall into this toxidrome that possess high toxicity include endosulfan (and its derivatives), 4-aminopyridine, and bifenthrin.[19] Because 4-aminopyridine is a potassium channel blocker, it has also been used as a pharmaceutical to improve motor activities in people with multiple sclerosis.
The most common chemical found in the anticoagulant toxidrome is warfarin, which is both a commonly used anticoagulant (blood thinner) and a pesticide. Analogs of warfarin, such as brodifacoum, bromodiolone, and dipacinone, are called "superwarfarin," as they have additional chemical functional groups which enhance the transport across the blood/brain barrier, making these even more lethally toxic than the parent compound.[20, 21, 22]

From a homeland security perspective, the only class of pharmaceuticals that currently has the potential to pose a significant threat is the opioid agonists. As has been recently reported, synthetic opioid use has reached epidemic proportions. Reports of deaths from opioid overdoses are reported in the media almost weekly. Because of the increased toxicity of some of these synthetic opioids, (some have been reported to be 10-100 times more potent than heroin) the possibility of some of these materials being used in an intentional release must be considered a potential threat. In addition, the use of synthetic opioids in the Moscow theater hostage incident in 2002, which resulted in over 100 injuries and fatalities, further demonstrates the threat posed by these materials.[23, 24]

Addressing the Risk

All of the toxic industrial chemicals, pesticides, and pharmaceuticals described in this article have legitimate and necessary uses. Any reduction in availability within the overall supply chain would be devastating to the chemical supply chain, manufacturers, and ultimately to the economy. Based

15 "40 C.F.R.: Appendix A to Part 355–The List of Extremely Hazardous Substances and Their Threshold Planning Quantities," Government Printing Office, ed. July 1, 2008. Retrieved October 29, 2011.

16 Thomas A. Unger, *Pesticide Synthesis Handbook* (Elsevier Science: 67–68, 1996). Print.

17 K. S. Whitlow, et al., "Tetramethylenedisulfotetramine: Old Agent and New Terror," *Annals of Emergency Medicine* 45, no. 6, 2005:609-613.

18 E. Croddy, "Rat Poison and Food Security in the People's Republic of China: Focus on Tetramethylene Disulfotetramine (Tetramine)," *Archives of Toxicology* 78, no. 1, (2004): 1–6.

19 EPA Reregistration Eligibility Decision for 4-aminopyridine, Environmental Protection Agency, September 27, 2007: 23. Accessed May 1, 2017.

20 "Warfarin Sodium," The American Society of Health-System Pharmacists, n.d. Accessed January 8, 2017, https://www.drugs.com/monograph/warfarin-sodium.html.

21 W. Ageno, et al., "Oral anticoagulant therapy: Antithrombotic Therapy and Prevention of Thrombosis, 9th ed: American College of Chest Physicians Evidence-Based Clinical Practice Guidelines," American College of Chest, Physicians (Chest, 2012: 141).

22 "Bromadiolone (Bromone, Maki) Chemical Profile 1/85," Pesticide Management Education Program, Cornell University, http://pmep.cce.cornell.edu/profiles/rodent/rodent_A_L/bromadiolone/bromad_prf_0185.html.

23 Susan B. Glasser and Peter Baker, "Russia Confirms Suspicions About Gas Used in Raid - Potent Anesthetic Pumped Into Theater - 2 More Hostages Die From Drug's Effects," *Washington Post*, October 31, 2002. Accessed May 1, 2017, http://bit.ly/2qrUj06.

24 Debora MacKenzie, "Mystery of Russian gas deepens," New Scientist, October 29, 2002. Accessed May 1, 2017. https://www.newscientist.com/article/dn2979-mystery-of-russian-gas-deepens.

on news reporting for the last six months of 2016, incidents involving toxic chemicals, both accidental and intentional, occur daily throughout the world and include both mass events as well as individual attacks.

There are currently several efforts within several agencies of the federal government to identify high-risk chemicals and improve both safety and security surrounding the use of these materials. In 2016, modifications to the Toxic Substances Control Act (TSCA) were implemented, which created a mandatory requirement for the EPA to evaluate existing chemicals with clear and enforceable deadlines, new risk-based safety standards, and increased public transparency for chemical information. The Chemical Facility Anti-Terrorism Standards (CFATS) program identifies and regulates high-risk chemical facilities to ensure they have security measures in place to reduce the risks associated with these chemicals.[25] Using a series of risk-based methodologies developed by the Department of Homeland Security, the program uses a quantitative risk-based assessment approach to categorize facilities and enhance security measures at the identified high-risk locations.

The Chemical Security Analysis Center (CSAC), the only DHS laboratory that was specifically established to address toxic chemical threats, analyzes the risk associated with toxic chemical releases, and identifies actions and capabilities needed to prevent and mitigate these releases. [26]In the 11 years since its inception, the CSAC has provided scientific and technical information surrounding both accidental and intentional releases to a number of federal, state, and local authorities, improving operational readiness and response.

Despite these very significant efforts, as well as others not mentioned here, there continue to be major gaps, both in terms of regulatory and operational capability, in providing the American public with protection against toxic chemical releases. While major improvements to toxic chemical holdings, use, and safety/security have been implemented as a result of both TSCA and the CFATS, both continue to have significant gaps that result in shifting the risk from one location/venue to another. This risk shift, while in most cases inadvertent, has resulted in moving some of the nation's most toxic chemicals from secure chemical facilities to more highly populated and unsecured locations. On the operational side, there are still major shortfalls in the detection or surveillance of, protection from, response to, and mitigation of a chemical event.

Many medical professionals refer to a "golden hour" when responding to exposures resulting from a chemical event.[27] Injuries and fatalities resulting from chemical exposure usually occur rapidly, and countermeasure deployment and use (including extensive decontamination) must occur quickly. Because of the unique nature of any toxic chemical release, no single countermeasure (detectors, masks, medical countermeasures, and/or mitigation) is sufficient. Rather, a synergistic approach to improve "ensemble"-based capabilities must be developed. Pre-incident surveillance, except at special events, is probably not possible due to the aforementioned rapid onset of symptoms. Better detectors can detect (and possibly identify) the wide range of chemical threats, but they have to be linked to response and to medical countermeasure deployment and treatment if they are to be used effectively.

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25 "Chemical Facility Anti-Terrorism Standards (CFATS)," Department of Homeland Security, July 20, 2016. Accessed May 1, 2017, https://www.dhs.gov/chemical-facility-anti-terrorism-standards.

26 "Chemical Security Analysis Center," Department of Homeland Security, n.d. Accessed May 1, 2017, https://www.dhs.gov/science-and-technology/csac.

27 K.L. Koenig and C.H. Schultz, Disaster Medicine: Comprehensive Principles and Practices (London: Cambridge University Press, 2009). Print.

Investigating Chemical Attacks in Syria

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In the early morning of August 21, 2013, dozens of videos began appearing on YouTube channels associated with Syrian opposition activists that showed large numbers of dead people in towns in eastern and western Ghouta, suburbs around the Syrian capital, Damascus. Emails and postings on social media claimed that a chemical weapons attack had killed hundreds of people. If true, it would be the deadliest chemical weapons attack in 25 years. With no access to the attacked areas and government and opposition blaming each other for the attacks, how does one establish the facts? Were these indeed chemical weapons attacks? If so, which chemical weapon was used? And perhaps most importantly, who was responsible? This article looks at how Human Rights Watch has investigated chemical attacks in Syria, including the use of information posted on social media.

The Syrian conflict is playing itself out on social media like no other armed conflict. Activists, journalists, medical personnel, first responders, and local residents are posting information about what they see and hear on Facebook and Twitter. There are literally hundreds of videos being uploaded to YouTube from Syria every single day.

Information posted on social media provides opportunities for human rights investigators that were unthinkable when we investigated the last known major chemical weapon attacks, which were conducted by Saddam Hussein's military in Iraq against the Iraqi Kurds, culminating in the Halabja massacre that killed thousands of civilians in 1988. Information on social media can help to establish when and where an incident happened, who the victims and the perpetrators were, and what kind of weapons were used – information that ultimately helps to answer whether there was a violation of international law.

But information on social media can be inaccurate, misleading, or false, just as an eyewitness account can. Photos can be manipulated and locations or dates can be erroneously posted. The use of doctored or false photos is not new, but the proliferation of such photos on social media increases the risk of relying on false information. For example, BBC accidentally used a 2003 photo taken in Iraq to illustrate a massacre that took place in Houla near Homs[1] – on May 25, 2012. Such errors have even occurred in official settings. Addressing the United Nations (UN) Security Council in December 2016, Syria's UN ambassador, Bashar Jaafari, branded a photo that he claimed showed a Syrian soldier helping a woman in Aleppo, except the photo was taken in Fallujah, in neighbouring Iraq, and featured a Popular Mobilisation Unit (PMU) fighter helping an Iraqi woman in June 2016.[2]

The immediate distribution of social media information also poses a challenge. The speed of social media today means that there is also pressure on human rights organizations to publish findings quickly, otherwise risking that narratives based on weak or false evidence take hold, thus making it harder to convince policymakers of the truth. Added to that are increasing efforts by various actors to muddle the picture by producing fake news or misleading propaganda.

By comparison, to document the Anfal campaign, which included the Halabja massacre, two researchers and an assistant spent a total of six months in the Kurdish areas on three

1 Chris Hamilton, "Houla massacre picture mistake," BBC *News*, May 29, 2012. Accessed May 3, 2017, http://www.bbc.co.uk/blogs/theeditors/2012/05/houla_massacre_picture_mistake.html.

2 Rose Troup Buchanan, "Syria's UN Ambassador Used A Photo From Iraq And Claimed It Was From Aleppo," *BuzzFeed News*, December 14, 2016. Accessed May 3, 2017, https://www.buzzfeed.com/rosebuchanan/syrian-ambassador-to-the-un-iraq-photo?utm_term=.ej1kOWPad#.ggW3091aK.

separate missions between April 1992 and April 1993, conducting approximately 350 in-depth interviews. To be effective, human rights organizations usually need to be much quicker in today's world.

However, it is absolutely vital that we get the facts right. While media outlets facing tight deadlines and cutthroat competition can sometimes publish "unconfirmed" photos and videos from important incidents, it is possible to verify information posted on social media. This is just as important as corroborating an eyewitness account. However, it requires cross-checking information from multiple sources, consulting with experts to evaluate this information, and, in the case of complex attacks, such as the ones in Ghouta, looking at different elements of the evidence, from the delivery mechanism to the medical symptoms of the victims.

The Delivery Mechanism: Verifying Videos and Photos

In 2013, chemical weapons struck two general areas about 16 kilometers apart in eastern and western Ghouta early in the morning of August 21.

Identifying the rockets that struck western Ghouta proved to be relatively straightforward based on videos and photos posted on social media or sent to us directly by activists. One video showed an expended rocket motor found on the street next to the Rawda Mosque in Moadamiyeh. The video clearly showed the 10 venture (exhaust nozzles) and electric contact plate of the rocket, which is a unique identification characteristic of the Soviet-made surface-to-surface 140 mm rocket known as the M-14. The video also showed the factory markings on the casing of the rocket, making the identification definitive. The 179 factory markings on the rocket refer to the Soviet-era "Factory 179" in Novosibirsk, one of the largest producers of artillery and rockets during the Soviet period, and a known manufacturer of the M-14 rocket.

A separate video shot on August 27 shows UN inspectors measuring and photographing this rocket motor, which confirmed that the remnant's length and width correspond with the dimensions of the M-14 rocket.

Identifying and understanding the rockets that struck eastern Ghouta required more work. Videos and photos of rocket remnants from eastern Ghouta showed remnants from a different type of rocket. The remnants did not match any weapons listed in standard, specialized, international, or declassified reference materials. In fact, the remnants seemed to stem from a rocket type that had not been documented before the outbreak of the current Syrian conflict.

An online community of weapons experts proved invaluable in developing an understanding of the mystery munition by sharing and analyzing photos and videos of the remnants. By August 25, one member had put together a rough sketch of the rocket and its dimension.

While the photos and video footage posted on social media gave a rough idea of the measurements of the rocket and how they worked, there were still many unanswered questions, such as their capacity to carry chemical agents. A local activist took high-resolution photos of the remnants accompanied by measuring tape, which provided more accurate information about the rockets. Based on this information we were able to estimate that the diameter of the rocket was approximately 330 mm. The photos also showed that the payload of the rocket consisted of a large, thin-walled container capable of holding 50-60 liters of liquid loaded into the payload via a plughole, and a small central tube with a suspected bursting charge at the front that would rupture the thin-walled container and distribute the vaporized liquid.

A crucial element when working with social media photos and videos is to verify where and when they were obtained. There are several steps we take to do this.

One of the first steps is to check whether the time and date of the social media postings are consistent with the alleged time and date of the attacks. This is not always completely straightforward. Twitter provides the time when something was uploaded in the time zone indicated in the settings, so there might need to be a conversion to the local time of the place where the attack took place. Facebook also usually indicates the time of posting in one's respective time zone. By inspecting the time element on a Facebook post, one can find the Unix timestamp, which is the number of seconds since January 1, 1970 (UTC). A converter can then provide the time of the post in UTC.[3]

YouTube's publication dates can sometimes be particularly deceiving; YouTube's computers automatically assign a date to each video based on the current time in California when the upload begins, which can differ from the date in the user's time zone.[4] Given that California is 10 hours behind Syria, this means that YouTube could stamp a video with a publication date that precedes the actual publication date. To verify the time and date a video was uploaded, one needs to extract the metadata of the video file. Amnesty International has developed a tool that greatly simplifies the process of extracting hidden data, including the time of posting, from videos on YouTube.[5]

This became particularly important with regards to one of the videos that showed victims from the August 21 attack but had a publication date of August 20, which led some, including a Russian spokesman,[6] to speculate that the attack was staged and somebody posted the video too early. When we extracted the actual upload time and date of the video, however, they show that the video was uploaded at 04:38:06 a.m. UTC on August 21, 2013, several hours after the attack had allegedly taken place.

A second step is to check whether photos have been posted online before. Google has a function that can conduct a reverse image search of a photo posted online or a photo that one uploads.[7] The results will then show if that photo has been posted anywhere else online. TinEye has a similar function.[8]

A reverse image search is a bit more cumbersome with video footage, but the Amnesty International tool mentioned above also extracts thumbnails from a video that can be used to conduct a reverse image search.

The photos for which we ran reverse image searches showed that they had not been posted online before.

A third step is to look for buildings, landmarks, or other objects in the photos or videos that can allow us to identify the location. Comparing such landmarks to satellite imagery or other photos and videos from the same location can verify the exact location. For one of the remnants of the weapon suspected of delivering the chemical agent in eastern Ghouta, several photos taken from different angles showed buildings in the background. Using five of these photos, Eliot Higgins identified the weapon's exact location between Zamalka and Ein Tarma,[9] the alleged area of the chemical attack.

The arrival of UN inspectors at the sites, several days after the attack, provided further confirmation of the location, as local activists filmed and photographed the UN inspectors examining remnants, photos and videos of

3 "Epoch Unix Time Stamp Converter," Dan's Tools, n.d. Accessed May 3, 2017, http://www.unixtimestamp.com/index.php.

4 Robert Mackey, "Confused by How YouTube Assigns Dates, Russians Cite False Claim on Syria Videos," *The New York Times*, August 23, 2013. Accessed May 3, 2017, https://thelede.blogs.nytimes.com/2013/08/23/confused-by-how-youtube-assigns-dates-russians-cite-false-claim-on-syria-videos.

5 Christoph Koettl, "YouTube Data Viewer," Citizen Evidence Lab, July 1, 2014. Accessed May 3, 2017, https://citizenevidence.org/2014/07/01/youtube-dataviewer.

6 David Jolly, "Russia Urges Syria to Cooperate in Chemical Weapons Inquiry," *The New York Times*, August 23, 2013. Accessed May 3, 2017, http://www.nytimes.com/2013/08/24/world/middleeast/syria-chemical-attack.html.

7 "Google Images," Google, n.d. Accessed May 3, 2017, https://images.google.com.

8 "Reverse Image Search," TinEye, n.d. Accessed May 3, 2017, https://www.tineye.com.

9 "Finding The Exact Location Of An Alleged Chemical Munition, And What It Could Mean," Brown Moses Blog, August 26, 2013. Accessed May 3, 2017, http://brown-moses.blogspot.fr/2013/08/finding-exact-location-of-alleged.html.

which had been posted immediately after the attack.

In addition, we interviewed eyewitnesses to confirm the locations where remnants were found. When we could, we reached out directly to the people who had posted the photos and videos to confirm the time, location, and circumstances under which they had obtained the footage. We then corroborated this with information from other local residents. Corroboration was made easier by the fact that Human Rights Watch has conducted investigations into a wide range of violations all over Syria since the conflict started – even before that – and we have a wide network of contacts that we reach out to, including in the areas that came under attack in Ghouta.

In western Ghouta, two local residents confirmed that several rockets had hit the area around the Rawda mosque on August 21, and that they saw remnants at the impact site similar to those in the videos. In eastern Ghouta, witnesses identified four locations where eight rockets had impacted. Local residents provided us with exact GPS locations for these locations.

The Chemical Agent

The precise identification of the specific chemical agent used in a chemical attack requires the collection of samples from weapon remnants, environmental samples, and physiological samples from those directly or indirectly exposed to the chemical agent. Subsequent specialized analyses of these samples can reveal the specific agent itself, or the reaction or degradation products characteristic of a specific agent.

In the absence of such testing, we had to rely on the rocket types used, photos and videos of the victims, and detailed interviews of eyewitnesses and medical personnel about the symptoms they observed. These elements allowed us to reach a preliminary, indirect, and circumstantial conclusion that sarin was the chemical likely used in the Ghouta attacks, a conclusion that was later confirmed by the UN investigation team.

The identification of the rockets allowed us to conclude that the weapons used were capable of delivering chemical agents. A declassified U.S. munitions catalogue and standard international reference materials published by Jane's Information Group indicated that the M-14 rocket found in western Ghouta could carry one of three warheads, one of which was a chemical warhead containing 2.2 kilograms of sarin. The high-resolution photos and measurements of the rockets that struck eastern Ghouta indicated that each rocket was capable of holding 50-60 liters of chemical agent as described above.

Social media photos and videos of the remnants supported the allegation of a chemical attack in another way, too. In none of the footage could we detect craters, fragments, or damage that we would expect to see if the rockets had carried high-explosive, incendiary, or other types of warheads.

Videos of people allegedly affected in the attack also pointed towards a chemical attack. The videos showed that several of the younger victims exhibited cyanosis, a bluish coloring on their face, especially around their eyes and mouth, which is consistent with suffocation or asphyxiation. The suffocation was likely either caused by excessive secretion of mucus and fluids in the lungs and air passages, damage to the part of the nervous system that supports breathing, or both. A majority of adult victims in these videos also showed signs of excessive secretions of fluids or mucus from the mouth and nose. Several of the patients shown in the videos were experiencing involuntary muscle spasms or convulsions. Furthermore, the victims in the videos did not exhibit any obvious indication of bodily trauma or excessive blood loss, which we usually observe with injuries due to explosive concussions, fragmentation, or incendiary devices, lending credibility to the allegation that the attack was chemical.

With the videos of the victims, we ran the same verification steps as with the videos of the remnants described above, trying to verify when and where the footage was obtained.

Again, we relied on eyewitness accounts to confirm the key elements in the videos and provide additional important information. None of the accounts describing the impact of the rockets are consistent with an attack using high explosive or incendiary payloads.

Eyewitness accounts were also important in connecting the rocket attacks to the deaths. One witness in western Ghouta, for example said that the rocket struck the first floor of a four-story apartment building. “Everyone in the building died in their sleep. It didn’t cause a lot of destruction,” he said. A witness in eastern Ghouta described seeing a man and a woman in a house some distance away from where the rocket had impacted, but that there was no damage to the building.

Interviews with medical personnel gave us a much more detailed description of the symptoms than what we could observe in the videos. Three local doctors told us that those affected by the attacks consistently showed clinical signs, including suffocation; constricted, irregular, and infrequent breathing; involuntary muscle spasms; frothing at the mouth; fluid coming out of noses and eyes; convulsions; red and irritated eyes; and pinpoint pupils (myosis). In addition, they reported that victims complained of nausea, dizziness, and blurred vision.

To ensure that we were interpreting the medical symptoms correctly, Human Rights Watch sought technical advice from Dr. Keith B. Ward, a respected expert on the detection and effects of chemical warfare agents, who reviewed first-hand and second-hand reports from local residents, the clinical signs and symptoms described by doctors, and the large number of videos that were taken of the victims of the August 21 attack.

The clinical signs we observed in the videos and the signs and symptoms of the victims commonly reported by others, including medical personnel, were not consistent with injuries due to explosive concussions, fragmentation, or incendiary devices; nor were they consistent with exposure to chocking/pulmonary, lachrymatory, incapacitating, vesicant/blister, or asphyxiant/blood agents, according to Ward. Rather, they were a strong indication that the victims were exposed to a toxic organophosphate chemical agent (i.e. “nerve agent”) which acts by inhibiting enzymes necessary to a properly functioning nervous system. The information that those affected exhibited myosis became particularly important, as it is a strong indication of the presence of a nerve agent. It was not always clear from photos and videos posted on social media if victims exhibited myosis, and the information from the medical personnel was crucial in this respect.

Syria was believed to possess at least two nerve agents, sarin and VX, in significant quantities. The fact that people were able to visit the sites of the attacks a few hours after the attack and handle remnants of rockets associated with the attacks without suffering signs and symptoms of exposure to nerve agent suggested that the nerve agent involved was more likely the less persistent and less toxic agent, sarin, rather than VX; this conclusion was also consistent with indications that sarin had been used even before the August 21 attack and was confirmed by the UN investigation.

Assigning Responsibility

Almost immediately after the chemical attack, opposition and government forces blamed each other for being responsible. The attack had occurred on a strategic area on the outskirts of Damascus held by the opposition. But the Syrian government and many of its supporters claimed that armed groups had cynically attacked their own areas to get the United States and other western powers to militarily intervene. This meant that any effort to assign responsibility had to look at the party that had the means to carry out such an attack. In particular, a key part of the question was who had access to the rockets used to deliver the chemical agents?

Declassified reference material listed the Syrian government as being in possession of the M-14 rocket that struck western Ghouta. As mentioned before, the rockets that struck eastern Ghouta were not listed in any reference material. However, the consistency in the design of the rockets suggested that they were industrially but locally produced. These mystery munitions were often referred to as improvised rocket-assisted munition (IRAM).

The high-resolution photos and measurements of the remnants establishing the diameter of the rocket as approximately 330 mm provided an important clue as to the launching system. These dimensions are compatible with the Iranian-produced 333 mm Falaq-2 launcher, or close copies and derivatives thereof. Iran, a close ally of the Syrian government, is believed to be the only country in the world to produce rocket launchers in the 333 mm category.

Were government forces using these types of rockets? Human rights investigators and other researchers, particularly Eliot Higgins, had been closely examining social media information about the various weapons used by all sides since the beginning of the conflict. These observers had identified rocket remnants similar to the eastern Ghouta mystery munition prior to August 21. In an article,[10] Higgins discussed the remnants of an unidentified rocket that had appeared in videos in January and June that year, several months before the Ghouta chemical attacks. In early August, footage of similar remnants was posted online with the claim that they were linked to a chemical attack in Adra.[11] The footage from the eastern Ghouta mystery munition showed that it was the same type of weapon.

Other videos, analyzed separately by Higgins[12] and Nic Jenzen-Jones,[13] a weapons expert, showed what appeared to be government forces firing the same type of rockets from Falaq-2 type launchers. While the videos of the launches are not related to the Ghouta chemical attacks – those attacks took place at night, while the launches in the videos took place during the day – they are very strong indications that Syrian government forces had been using this particular type of rockets and their corresponding launchers several months before the Ghouta chemical attack.

Almost just as important as the determination that government forces were in possession of both rocket types used in the Ghouta attacks and their corresponding launch systems was the observation that no footage had emerged showing opposition forces using these weapons systems prior to the Ghouta attack. Opposition forces did get a hold of and use weapons from Syrian government forces, and were usually quite eager to show off their possession and use of these weapons to their supporters by posting videos online, but there was no footage of opposition forces using either the M-14 or the IRAMs used in eastern Ghouta, nor their launching systems.

We are also not aware of any footage of opposition forces using these two weapons system after the Ghouta attack, with one exception, which, upon examination, appeared to be a staged attempt.

On September 16, 2013, a user uploaded three videos to the website LiveLeak, claiming that it was filmed on August 21. The videos show people in gas masks firing the same rockets that hit eastern Ghouta. A voice in the video says the name of the group, the date, and the codename for the operation. A black flag with white Arabic letters shows the same name of the group.

This could have been very important evidence, not only because the video appeared to show that opposition forces possessed the weapon that was used, but also because it appeared to show that they were the ones firing the rockets that struck eastern Ghouta that night.

However, applying the same source verification process to these videos as we did to other videos almost completely eliminated their value. The videos were uploaded by a user who created his accounts on LiveLeak and YouTube that day, uploaded no other videos, and has not conducted any other activity on the accounts since. The user claimed that Kurdish

10 "A Mystery Munition - Syrian Army DIY Rockets?," Brown Moses Blog, June 13, 2013. Accessed May 3, 2017, http://brown-moses.blogspot.fr/2013/06/a-mystery-munition-syrian-army-diy.html.

11 "DIY Weapon Linked To Alleged Chemical Weapon Attack in Adra, Damascus," Brown Moses Blog, August 6, 2013. Accessed May 3, 2017, http://brown-moses.blogspot.fr/2013/08/diy-weapon-linked-to-alleged-chemical.html.

12 "Video Shows Assad's Forces Loading, Firing, Munition Linked To Chemical Attacks," Brown Moses Blog, August 28, 2013. Accessed May 3, 2017, http://brown-moses.blogspot.fr/2013/08/the-smoking-gun-video-shows-assads.html.

13 N. R. Jenzen-Jones, "Alleged CW munitions in Syria fired from Iranian Falaq-2 Type launchers," The Rogue Adventurer, August 29, 2013. Accessed May 3, 2017, https://rogueadventurer.com/2013/08/29/alleged-cw-munitions-in-syria-fired-from-iranian-falaq-2-type-launchers.

Peshmerga forces had found the videos on the cellphones of three killed Syrian terrorists, but there is no information corroborating this, and Kurdish Peshmerga sources say they have not heard any information about this. The timing of the release of the videos, the same day that the UN released its first report on the attack, seems suspicious. There are several other elements raising questions about the credibility of the footage. Ultimately, we were not able to find any information independently corroborating these videos.

In a second line of inquiry for determining responsibility, we looked at the ranges and incoming directions of the rockets to try to determine where the rockets were fired from. Again, analyzing the M-14 rocket proved easier. Reference material indicates that the M-14 rocket has a minimum range of 3.8 kilometers and a maximum range of 9.8 kilometers. Based on the range alone, without assessing the direction, possible launch areas included important government military bases such as the Mezzeh Military Airport and the Syrian 4th Armored Division base. The range alone is not conclusive, however, as some opposition-controlled territory is within the possible launch zone.

However, the UN report published on September 16 included information about the likely trajectory of the projectiles.[14] According to the report, two of the rocket impact sites that the inspectors assessed in western Ghouta had bearings of 34 and 35 degrees. Combining the minimum and maximum ranges of the M-14 rockets with the UN's information about the trajectory leaves all the possible launch sites for the M-14 rockets in government-controlled territory and near the government military bases mentioned above.

With regards to the IRAMs that struck eastern Ghouta, the UN investigation determined that at least one of the rockets had a 285 degrees bearing (coming from west-northwest). If the IRAMs had a range similar to the M-14, a 285 degrees bearing would point back to the same government military bases as the M-14 rockets.

Because there is no reference material for the IRAM rocket, however, we don't know its range. The reconstruction of the rocket showed that it had a non-aerodynamic design, indicating that the rocket would be relatively short-ranged and incapable of accurate targeting. Some observers have calculated that the range might be as short as 2-2.5 kilometers,[15] but there are still many elements that are unknown, including, for example, whether the rockets had nose-cones, which would impact the range.

For the IRAM, there is also a question about the 285 degrees direction given by the UN. One video shows UN inspectors measuring a rocket remnant stuck in the ground near a wall. Locating the remnant on the map and estimating the angle between the rocket remnant and a nearby wall indicate a more northern incoming direction than the UN's 285 degrees. However, without knowing more about the UN measurement, including whether the rocket remnant in the video is the one on which the investigators based their directional estimate, it is difficult to be conclusive.

The various options for the IRAM's range and incoming direction do not, however, make a difference as to the question of responsibility. Careful analysis of video footage captured during the period immediately prior to the August 21 attack shows that both government forces and opposition forces were within a 2-2.5 kilometers range to the north-northwest of the impact sites.[16]

In addition to the weapon systems used, oth-

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14 United Nations, General Assembly Security Council, *Report of the United Nations Mission to Investigate Allegations of the Use of Chemical Weapons in the Syrian Arab Republic on the alleged use of chemical weapons in the Ghouta area of Damascus on* 21 August 2013, A/67/997–S/2013/553 (September 16, 2013). Accessed May 3, 2017, http://undocs.org/A/67/997.

15 C. J. Chivers, "New Study Refines View of Sarin Attack in Syria," *The New York Times*, December 28, 2013. Accessed May 3, 2017, http://www.nytimes.com/2013/12/29/world/middleeast/new-study-refines-view-of-sarin-attack-in-syria.html.

16 Eliot Higgins, "Identifying Government Positions During The August 21st Sarin Attacks," Bellingcat, July 15,

er elements, such as the large-scale nature of the attacks, the large amount of nerve agent used, and possibly specific chemicals that the UN detected at the impact sites also point towards government responsibility for the attacks.

Continued Chemical Attacks

Following the UN report that conclusively established that sarin had been used in the attack on eastern and western Ghouta, and investigative reports by non-governmental organizations and open-source investigators that provided strong indications that it was the Syrian government that was responsible for the chemical attacks on August 21, the UN Security Council demanded that Syria join the Chemical Weapons Convention and destroy its chemical weapons stockpile. The UN announced on June 23, 2014, that it had removed all chemical weapons that the Syrian government had declared.

Starting in April 2014, however, government helicopters started dropping munitions filled with chlorine on opposition-controlled territory. These attacks posed different challenges compared to the Ghouta chemical attacks. Because the munitions were dropped from helicopters, it was less difficult to establish responsibility – only the Syrian government operated helicopters in 2014 – but it became more important to, for example, establish that the munitions were dropped from helicopters. Using the same combination of information analysis, including photos and videos posted on social media, interviews with eyewitnesses, and consultations with experts on weapons and chemicals, we published reports on these attacks in May 2014,[17] April 2015,[18] June 2015,[19] September 2016,[20] and February 2017.[21] Using the same methodology, we also documented that the so-called Islamic State used mustard gas on at least two occasions.

Importance of Social Media

At least 196 videos were uploaded to YouTube that related to the Ghouta chemical attacks on August 21. More videos, photos, and other pieces of information were posted on other social media platforms, such as Facebook and Twitter. This information was extremely important to establish key aspects of the chemical attacks.

Information on social media alone, however, would not have allowed us to draw the strong conclusions that we eventually did about the delivery mechanism, the chemical used, and who was responsible. Interviews with eyewitnesses, including medical personnel, higher-resolution photos with measurements sent to us directly, and extensive consultations with weapons and chemical experts were crucial to gain a more detailed understanding of how the weapons systems worked, linking the rocket remnants to victims, and better understanding the symptoms that victims exhibited, allowing us to identify the chemical used. Maybe just as important, interviews with witnesses allowed us to verify and corroborate information posted on social media. For the Ghouta attack, combining traditional human rights interviews and analysis with verification of social media information proved key in reaching our legal conclusions.

2014. Accessed May 3, 2017, https://www.bellingcat.com/news/mena/2014/07/15/identifying-government-positions-during-the-august-21st-sarin-attacks.

17 "Syria: Strong Evidence Government Used Chemicals as a Weapon," Human Rights Watch, May 13, 2014. Accessed May 3, 2017, https://www.hrw.org/news/2014/05/13/syria-strong-evidence-government-used-chemicals-weapon.

18 "Syria: Chemicals Used in Idlib Attacks," Human Rights Watch, April 13, 2015. Accessed May 3, 2017, https://www.hrw.org/news/2015/04/13/syria-chemicals-used-idlib-attacks.

19 "Syria: New Chemical Attacks in Idlib," Human Rights Watch, June 3, 2015. Accessed May 3, 2017, https://www.hrw.org/news/2015/06/03/syria-new-chemical-attacks-idlib.

20 "Syria: New Deadly Chemical Attacks," Human Rights Watch, September 28, 2016. Accessed May 3, 2017, https://www.hrw.org/news/2016/09/28/syria-new-deadly-chemical-attacks.

21 "Syria: Coordinated Chemical Attacks on Aleppo," Human Rights Watch, February 13, 2017. Accessed May 3, 2017, https://www.hrw.org/news/2017/02/13/syria-coordinated-chemical-attacks-aleppo.

Chemical Weapons Use in Jebel Marra – Analysis of Symptoms and Potential Agents Used

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Disclaimer: *Images within this article (pp. 26-27) may be considered disturbing or graphic to some readers.*

Conflicts within failed states haunt our modern times. The use of chemical warfare agents[1] during these conflicts pose a particularly deadly and increasingly common problem because of their ready availability and ease of delivery. Where once only national governments concerned themselves with detection of Chemical Weapons Convention (CWC)[2] violations, now non-governmental organizations (NGOs) strive to document such violations. Their accurate evaluation of evidence of alleged use of chemical weapons is challenging for several reasons.

Despite the technical difficulties, there have been examples of NGOs documenting the use of chemical warfare agents. Human Rights Watch and their technical consultants successfully evaluated these kinds of data and produced reports that convincingly document illegal use of the nerve gas sarin[3, 4, 5] and chlorine gas[6] in Syria. Individual medical practitioners have also provided significant evidence of chemical weapons use. Based only upon analyses of 210 YouTube videos taken during chemical attacks in the outskirts of Damascus in 2013, Rossman et al. demonstrated that clinical syndromes could be successfully evaluated using only videos uploaded to social media.[7]

We addressed allegations of the use of chemicals in Jebel Marra, an area Darfur, Sudan and provided briefly our technical approach in both report[8] and editorial[9] form. Analysis of these alleged attacks was particularly challenging because of

1 K. Ganesan et al., "Chemical Warfare Agents," *Journal of Pharmacy & BioAllied Sciences* 2, no. 3 (September 2010): 166–178, http://www.jpbsonline.org/article.asp?issn=0975-7406;year=2010;volume=2;issue=3;spage=166;epage=178;aulast=Ganesan.

2 "Chemical Weapons Convention," Organisation for the Prohibition of Chemical Weapons, n.d. Accessed January 17, 2017, https://www.opcw.org/chemical-weapons-convention.

3 "Attacks on Ghouta: Analysis of Alleged Use of Chemical Weapons," Humans Rights Watch, September 10, 2013. Accessed January 16, 2017, https://www.hrw.org/report/2013/09/10/attacks-ghouta/analysis-alleged-use-chemical-weapons-syria.

4 "Death by Chemicals: The Syrian Government's Widespread and Systematic Use of Chemical Weapons," Human Rights Watch, May 1, 2017. Accessed May 4, 2017, https://www.hrw.org/report/2017/05/01/death-chemicals/syrian-governments-widespread-and-systematic-use-chemical-weapons.

5 Co-author Dr. Keith Ward served as a technical consultant for these reports.

6 "Syria: New Deadly Chemical Attacks. Strong Security Council Action Needed," Human Rights Watch, September 28, 2016. Aaccessed January 14, 2017, https://www.hrw.org/news/2016/09/28/syria-new-deadly-chemical-attacks.

7 Y. Rosman, et al., "Lessons Learned From the Syrian Sarin Attack:Evaluation of a Clinical Syndrome Through Social Media", *Annals Internal Medicine* 160, no. 9 (May 2014):644-648, http://annals.org/aim/article/1867059/lessons-learned-from-syrian-sarin-attack-evaluation-clinical-syndrome-through.

8 "Scorched Earth, Poisoned Air. Credible evidence of children killed and maimed by horrific chemical weapons attack in Darfur," Amnesty International, n.d. Accessed January 14, 2017, https://www.amnesty.org/en/latest/news/2016/09/chemical-weapons-attacks-darfur.

9 Jonathan Loeb, "Did Sudan use chemical weapons in Darfur last year?," *Bulletin of the Atomic Scientists*, January 17, 2017. Accessed January 18, 2017, http://thebulletin.org/did-sudan-use-chemical-weapons-darfur-last-year10402.

our inability to access the area. Here we provide additional information about our analysis in detail sufficient enough to allow others to better understand how we reached the conclusions in our earlier report.

Attacks in Jebel Marra, Darfur

Between January and September 2016, Sudanese government forces carried out a large-scale military campaign in the Jebel Marra area of Darfur, Sudan. The government launched the campaign to attack and gain control over positions held by members of the Sudan Liberation Army/Abdul Wahid (SLA/AW), and, in turn, to put an end to the "rebellion" in Darfur. Credible and consistent reporting about the campaign was extraordinarily difficult to obtain as Jebel Marra, a 5,000 km2 volcanic massif in the center of Darfur, is geographically isolated and only a fraction of the area has even sporadic cellphone coverage. Moreover, the government denied meaningful access to the attacked areas to all journalists, human rights investigators, humanitarian actors, and members of the African Union/United Nations Hybrid Operation in Darfur (UNAMID).

In February 2016, Amnesty International initiated a remote investigation to obtain information about the impact of the violence on the civilian population living inside Jebel Marra. 231 people were interviewed by phone, including 184 survivors and witnesses of attacks and 22 members of the SLA/AW. The investigation unearthed many serious violations of international humanitarian law and international human rights law by Sudanese government forces, including the unlawful killing of men, women, and children, the abduction and rape of women, the forced displacement of civilians, and the looting and destruction of civilian property, including entire villages.

The investigation also unearthed evidence suggesting that Sudanese government forces had repeatedly used chemical weapons. Amnesty International estimates that between 200 and 250 people may have died as a result of exposure to the chemical weapons agents, including many children.

Using testimonial and photographic evidence provided by Amnesty International investigators, we addressed the allegations of the use of chemical weapons agents and provided our technical assessment in both report[10] and editorial[11] form. We concluded that there was credible evidence to strongly suggest that chemical weapons agents were used in the attacks documented by Amnesty International. Here, we provide additional details about our assessment that support our conclusion that many injuries to victims of these attacks were caused by exposure to chemicals of some sort. We discuss a variety of chemicals that were considered during our analysis, including some, such as white phosphorus, that we excluded from our initial report because its effects are largely inconsistent with the data we analyzed. We also address in some detail our reasons for excluding various alternatives that others have suggested might provide a better explanation for the wounds suffered by victims of the Jebel Marra attacks.

Amnesty International's Investigation and Limitations

To provide a highly reliable, unambiguous identification of specific chemical agents used in the alleged chemical attacks documented by Amnesty International would require the collection and analysis of biological specimens from victims exposed to the chemical agents. Chemical analyses of soil and water samples as well as remnants of weapons used in the attacks would have enhanced the reliability of our identification. Unfortunately, access to Jebel Marra is severely restricted, so it was not possible for Amnesty International to obtain such samples. The data available for our investigation was therefore limited to testimonial and photographic evidence.

Testimonial evidence was gathered from extended phone interviews with 57 residents of Jebel Marra, 47 civilians and 10 members of SLA/AW. The interviewees included survivors of 32 alleged attacks as well as 10 caregivers who cared for survivors and victims. The interviewees were from dozens of different locations in Jebel Marra and were identified and contacted through nu-

10 "Scorched Earth, Poisoned Air. Credible evidence of children killed and maimed by horrific chemical weapons attack in Darfur."

11 "Did Sudan use chemical weapons in Darfur last year?"

merous independent entry points into the population.

The vast majority of the interviews were translated from Fur, a local, non-written language, to English by an experienced translator, albeit without any specialized knowledge of medical terminology.

Our photographic data was also limited. Video recording devices were largely unavailable and photos were collected by only a few of the caregivers. Cellphone service is limited in this remote region, and the data was often recorded days, weeks, or even months after the attacks. Our analyses considered these delays and we assumed that victims' initial wounds may have partially healed or had become infected before photos were taken. Most survivors of the attacks had no access to adequate care. Indeed, some photos show clear indications of likely secondary infections. Clearly, these images are not likely to conform to the standard "textbook images" of chemical agent wounds taken soon after an attack.

The Investigation's Findings

Survivors reported that the suspected chemical weapons agents were delivered predominantly by bombs and occasionally by rockets. The vast majority of survivors reported that the smoke released from the bombs and rockets that contained alleged chemical weapons agents changed color after it was discharged. A small minority reported that the smoke was initially black and then disappeared. Of those who reported that the smoke changed color, nearly all stated that the smoke started off very dark, usually black, and then proceeded to get lighter in color until it turned grey or white.

Although odor is not considered a reliable indicator of any specific chemical warfare agent, every survivor described the smell of the smoke as noxious. Many were unable to articulate the smell beyond the fact that they found it intensely disagreeable; witnesses often said that they had never experienced anything like it before or that it was "unnatural." Several survivors described the smell as putrid or musty. Several described as "rotten," "like rotten eggs," "hot" or "hot like pepper," or some combination thereof. Four survivors described the smell as similar to an insecticide, chlorine, or sulfur.

In addition to affecting victims, the smoke from these rockets and bombs also affected animals that were exposed. Several survivors said that large numbers of birds and other animals, including donkeys, died after coming into contact with smoke containing the alleged chemical weapons agents. Survivors and caregivers described a wide variety of ailments that victims of the attacks experienced during the hours and days after exposure to the alleged chemical weapons agents. In general, children were more severely affected than adults, which is an expected finding for a chemical warfare agent release. Children have significantly higher lung surface area-to-volume ratios than adults due to their size and are therefore more likely to receive larger relative doses of these agents than adults. Furthermore, chemical warfare agents are denser than air and settle closer to the ground, concentrating in the air that children breathe. Several survivors reported that their young children experienced a regression in their motor functions and mental capabilities after exposure to the alleged chemical weapon agents, including an inability to walk or speak despite having previously been able to do so.

Two of the most common symptoms of exposure to the smoke, which the vast majority of survivors reported experiencing and which the caregivers almost always reported observing in those they treated, were gastrointestinal in nature: very severe, often bloody vomiting and diarrhea. Vomiting and diarrhea both commenced very soon after exposure, with most survivors stating that they commenced immediately or within 30 minutes of exposure. According to the caregivers, the diarrhea did not respond to antibiotics which are normally used to treat diarrhea in this region indicating that the diarrhea was due to a chemical and not secondary to an infection. Diarrhea and vomiting ultimately led to dehydration resulting in death in numerous instances, according to both survivors and caregivers.

Most victims and caregivers described physical changes to victims' skin that developed between one hour and one day after exposure. The changes reported by survivors and caregivers included severe blisters, rashes, and severe pruritus (itchiness). In most cases, the victims' skin reportedly hardened, changed color to white, black, or green, and subsequently fell off. Changes to the skin often occurred very soon after exposure, normally within an hour; however, many caregivers reported that changes to the skin occurred the following day. These changes could have been caused by direct contact with corrosive or caustic components of the smoke, or may have resulted from systemic exposure to chemicals in the smoke following dermal or inhalational absorption.

Ocular and respiratory disturbances were described in most exposures. Survivors described watering eyes and ocular pain while caregivers frequently described physical changes to the victims' eyes, including changes to eye color, bulging eyes, constant discharge of white or clear liquid from the eyes, constant itchiness, spots under the eyelids, and a reduction in vision. Several survivors lost their vision. Survivors and caregivers also reported a variety of respiratory problems that occurred shortly after exposure to the alleged chemical weapons agents, including severe coughing, difficulty breathing, and lung infections. Suffocation was among the most common causes of death for victims of the alleged chemical weapons attacks.

Reproductive effects were observed after exposure to the smoke during these attacks. Miscarriages among those exposed were commonly reported by witnesses and caregivers; the hundreds of miscarriages that were reported were often described as much bloodier than normal miscarriages. The miscarriages reportedly occurred either on the same day or within a few days of the exposure to the alleged chemical weapons agent.

Of particular interest were the reported changes in bodily odors and urine color. Survivors and caregivers reported dramatic changes to the smell of the breath of those exposed to the suspected chemical weapon agents. The smell of the breath was always reported to be extraordinarily disagreeable and often characterized as unnatural. Many victims and nearly all caregivers reported dramatic changes to the color of urine, usually to yellow/orange and then to red/maroon. They also reported that the odor of victims' urine and stool changed significantly and was unpleasant. Changes in bodily odors are indicative of exposure to chemical agents while changes in urine color might represent the presence of chemicals in urine or damage to the kidneys or liver.

Numerous other clinical signs and symptoms were commonly described by both caregivers and survivors. It was often reported that bodies, particularly of children, were swollen, indicating edema or fluid filling of tissues. Caregivers and parents of child survivors reported that children experienced a substantial loss in appetite after being exposed to the alleged chemical weapons agents. Several children reportedly refused to eat after being exposed and died from, presumably, malnourishment. Several adult survivors also reported experiencing a loss of appetite in the aftermath of an attack. Many victims experienced involuntary muscle contractions and had seizures. Most of the people who had seizures subsequently died. Numerous victims were also reportedly rendered unconscious as a result of exposure to the chemical weapon agents.

Initial Analysis

Our initial analysis of photographs and eyewitness testimony convinced us that the injuries caused by these attacks were most likely caused by exposure to chemicals rather than by concussive or thermal effects, or due to shrapnel. We found a dearth of information about how chemical agents affect people with dark skin, how wounds caused by chemical agents progress in the absence of appropriate medical care, and how secondary infections affect wound presentation long after the initial injury. As mentioned above, ideally, we would have analyses of environmental samples and biological specimens to include in our investigation into the identity of chemicals used in these attacks. The remoteness of and restricted access to the Jebel Marra region precluded these important data.[12,13] Our analysis and conclusions are therefore based upon a necessarily more limited set of input. Some readers of our earlier report have criticized our drawing conclusions based upon these limited data. We remain convinced that a thorough analysis of the available data support our initial conclusions

12 G. Winfield, "Leader: Willie Pete," CBRNe World, October 2016. Accessed May 2, 2017, http://www.cbrneworld.com/_uploads/download_magazines/Leader_Oct16.pdf.

13 J. P. Zanders, "Allegation of chemical warfare in Darfur," *The Trench*, February 1, 2017. Accessed May 2, 2017, http://www.the-trench.org/darfur-chemical-warfare.

and here we present our more detailed analysis of the evidence that indicates that Jebel Marra was subject to multiple chemical warfare agent attacks in 2016.

These initial assessments were included in the Amnesty International report "Scorched Earth, Poisoned Air" along with our general conclusions as follows:

> Dr. Keith Ward wrote: "I conclude that the clinical signs and symptoms of many of the victims are most consistent with their being exposed to a chemical substance capable of causing blisters (vesicles) and similar lesions. There is a class of chemical-warfare agents called vesicant or blister agents; this class includes sulphur mustard (the most commonly employed), nitrogen mustards (mostly used today in industry and medicine), Lewisite, and phosgene oxime. Victims exposed to one or more of these chemical-agent vesicants might exhibit many of these same signs and symptoms.
>
> Many of the observations reported by the interviewees, however, are not those we normally associate with exposure to chemical-agent vesicants. Thus I cannot rule out the possibility that victims of these attacks have been exposed to a combination of other chemicals instead of or in addition to blister agents. These other chemicals might include riot-control agents in very high concentrations, hydrogen sulphide gas, heavy metal poisons, biological toxins, strong inorganic acids and bases, and other corrosive chemicals. The frequently seen pattern of scattered individual circular lesions also suggests either spatter from hot liquid (which could also be responsible for the extensive skin denudation in some areas with marked sparing of other areas) or else an infectious process. The most commonly reported clinical signs and symptoms however are not consistent with spatter of hot liquids. More specific identification of any chemicals involved in these attacks must await more detailed analysis of tissue samples recovered from the victims and from soil samples in areas near the sites of the attacks. But it seems very clear, based upon the environmental descriptions of the attacks, the photographic evidence coupled with the reported clinical signs and symptoms, and after extensive discussions with medical doctors familiar with injuries caused by exposure to chemical and biological warfare agents that the wounds of these victims are not due simply to the effects of conventional explosive or incendiary weapons of war."
>
> Dr. Jennifer Knaack wrote: "Victims experienced a variety of symptoms that appear to be the result of chemical exposures. Much of the photographic and testimonial evidence is consistent with vesicant, or blister agent, exposure. Agents in this class include sulphur mustard, lewisite, and nitrogen mustard. Evidence that supports vesicant exposure includes: deep circular lesions often appearing in groups, blisters described as having formed several hours after exposure, facial edema or swelling, hyperpigmentation surrounding some lesions with areas of hypopigmentation, and blister distribution around warm and moist areas such as the buttocks and groin. It is of note that the lesions on victims' bodies are described as being difficult or impossible to treat and many of the photographed wounds appear infected. Some wounds were described as not healing. Vesicants inhibit activities of the immune system and so secondary infection of blister wounds is common, especially without appropriate antibiotic therapy, and lesions are usually slow to heal. Some select biological toxins can also cause similar symptoms and should not be ruled out. For example, T-2 trichothecene mycotoxin, historically known as "yellow rain," can cause symptoms similar to those seen in Jebel Marra including vomiting, diarrhea, itching, rash, blisters, conjunctivitis, coughing, and other respiratory ailments. Severe exposure to other chemicals, such as pesticides and tear gas, can also cause blister formation and some of the other observed symptoms, so it is imperative that clinical specimens and environmental samples be analyzed to positively identify the agent of exposure. Without these tests, it is not possible to definitively attribute these symptoms to any specific chemical. Other symptoms that were frequently described include changes in urine color and odor on breath and faces. These symptoms are indicative of arsenic exposure. Lewisite is an arsenic-containing vesicant, so it is possible that these symptoms were caused by lewisite, potentially mixed with sulphur

mustard. Arsenical pesticides, among other arsenic-containing chemicals, can also cause these symptoms and should not be ruled out. Again, confirmation of exposures through laboratory testing is required to positively identify arsenic exposure.

Not all symptoms and testimonials are consistent with vesicant exposure. For example, some interviewees described an odour of rotten eggs which indicates the presence of a sulphur-containing chemical such as sulphur dioxide or hydrogen sulphide. Sulphur dioxide can produce some exposure symptoms that were observed in Sudan and should not be ruled out. Hydrogen sulphide, however, is not likely to cause these symptoms

Because testimonial and photographic evidence is not necessarily consistent with exposure to a single chemical, it is possible that victims were exposed to different chemicals during different times or to a combination of chemicals. Regardless of the specific chemical of exposure, it is evident that chemical exposure occurred. Positive identification of the agent of exposure can only be made through laboratory testing of victim specimens and environmental samples. These specimens and samples should be collected as quickly as possible as these agents, and biomarkers of their exposure, can only be detected for a limited amount of time."

Evaluation of Chemical Weapons Use Allegations

The most relevant evidence for our conclusions came from witness testimonies, not from photographs. Some witnesses were themselves victims of these attacks and others were caretakers. The strongest evidence that victims' wounds were caused by chemicals came from descriptions of victims who escaped unscathed from the immediate effects of the rocket or bomb attacks, only to develop wounds hours or days later. Often times, these wounds developed on areas of the body that were covered by clothing such as the groin or buttocks. The development of wounds in these specific regions is indicative of chemical exposure. These clinical signs and symptoms that followed exposure could have come from chemicals that entered the bloodstream or were activated in these warm, moist regions of the body. Conventional weapon injuries always occur in conjunction with the initial blast and do not develop over time or on clothed regions of the body without causing destructing of clothing. No testimonial evidence indicated that wounds formed from blasts during the attacks, or that clothing was destroyed when these wounds developed. Based on this evidence, it was clear to us that exposure to a chemical agent occurred. Identification of the specific causative agent required a deeper analysis of testimonial evidence describing signs and symptoms of exposure, as well as analysis of wound characteristic based on photographic evidence.

In addition to descriptions of the timeline for wound development, clinical signs and symptoms described by victims and caretakers were also consistent with exposure to a chemical warfare agent. As previously described, gastrointestinal disturbances were reported by nearly all victims and developed within minutes of exposure. These disturbances included nausea, vomiting, and diarrhea. Diarrhea often became bloody and caretakers reported that feces and urine developed a "rotten" odor. Such gastrointestinal complications could arise from direct damage to the gastrointestinal tract by chemicals or from systemic exposure to a chemical. Because of the rapidity of the onset of gastrointestinal symptoms and because direct exposure of these tissues to chemicals would require ingestion of the chemicals, it is highly like that these symptoms represent systemic exposure either through inhalational or dermal routes.

Ocular and respiratory disturbances were also commonplace among most victims. Severe ocular and respiratory disturbances developed within minutes following exposure to the toxic smoke. These conditions included conjunctivitis, lachrymation (often with white- or red-colored discharge), coughing with chest tightness, and difficulty breathing. Ocular effects persisted even after victims were removed from areas with smoke and often resulted in corneal ulceration, changes to sclera color (often to brown, red, or green and possibly an indicator of blood or liver disorders), and edema. Respiratory symptoms also persisted long after removal from contaminated air. Caretakers of victims reported lung infections and severe coughs, often with elevated respiratory rates. Of note was that many victims were described as having breath that smelled "rotten" or "musty." For many victims, respiratory distress was present many months after exposure. Many toxic chemicals can cause ocular and respiratory disturbances, but these symptoms usually dissipate upon moving victims to fresh air. However, many chemical warfare agents such as vesicants are known to cause severe and persistent ocular and respiratory conditions such as those experienced by the Jebel Marra victims. Due to their non-specific effects on ocular and respiratory systems, it is not possible to determine a causative chemical warfare agent based on these symptoms.

Dermal effects resulting from exposure to the smoke were common and severe. Immediately following exposure intense itching, or pruritus, was described. This sensation persisted, in many cases, several days post-exposure. Blisters developed on the skin of all victims between several hours and a few days after exposure and were described as containing a clear fluid. The blisters eventually unroofed to form open wounds that were described as not healing. Many cases of skin color changes, from white to black, and hardening of the skin were described. Necrotic skin sloughing was frequently described by victims and caretakers. It is important to note that, in all cases, dermal effects of exposure, with the exception of pruritus, developed after the victims were moved to an area clear of smoke and that some effects, like blister formation, took several days to develop. None of the wounds we attribute to chemical warfare agent exposure occurred immediately during the attacks, nor could they be attributed to physical damage from blasts or shrapnel. Additionally, none of the dermal wounds were caused by thermal burns from the smoke, as would be expected from a smoke like white phosphorus.

Evidence of Vesicant Agents

Both testimonial and photographic evidence support the use of vesicants, or blistering agents, in the Jebel Marra attacks. Almost all victims and caretakers described the formation of blisters on various parts of victims' bodies, though the timeline varied from nearly immediate formation to blister development occurring after several days. While many chemicals can cause blistering, a class of chemical warfare agents called vesicants is characterized by its ability to cause blistering. One of the agents in this class, sulfur mustard, causes delayed blistering that can take up to several days after exposure to develop. Another agent in this class, lewisite, causes almost immediate pain and blistering. While lewisite use has not been confirmed on the battlefield, sulfur mustard is considered the most commonly used chemical warfare agent. Exposure to sulfur mustard and other vesicants results in the development erythema around one hour after exposure.[14] Reddening of victims' skin was not described as a result of exposure to smoke in the Jebel Marra attacks, though the dark skin tone of victims may have obscured any reddening. Furthermore, the progression of sulfur mustard wounds on dark-colored skin has not been adequately studied, so erythema may not be a predominant clinical sign of exposure in certain populations. We conclude that sulfur mustard and, possibly lewisite, were used in these attacks.

Figure 1: Circular wounds that formed after exposure to chemical smoke during an attack in the Jebel Marra region of Darfur in 2016. The wounds appear to be of unroofed blisters. Additional, small clusters of blisters appear at the upper left side of the photo. These wounds are indicative of exposure to sulfur mustard agents.

Several pieces of photographic evidence corroborated reports of blistering and included visible evidence of large, roughly circular blisters that had, in most cases, already burst (Figures 1 and 2). In Figure 1, a patch of small blisters is visible surrounding a larger, circular wound that appears to be an unroofed blister. Small blisters that coalesce into individual large blisters are

14 Centers for Disease Control and Prevention, "Sulfur Mustard: Blister Agent," Emergency Response Safety and Health Database, n.d. Accessed March 30, 2017, https://www.cdc.gov/niosh/ershdb/emergencyresponsecard_29750008.html.

characteristic of sulfur mustard exposure. Also supportive of exposure to sulfur mustard was the location of wounds to the buttocks and groin areas in many photos (Figure 3). Circular-shaped wounds localized in these warm, moist regions of the body are consistent with exposure to sulfur mustard which is activated by water from perspiration in warm areas of the body. Additional descriptions of severe conjunctivitis, respiratory issues (including coughing and lung infections), and swelling of the eyes and face were consistent with exposure to vesicant agents. These conditions and physical wounds were described as not healing which is characteristic of exposure to sulfur mustard, an agent known to reduce functions of the immune system. Nausea, vomiting, and diarrhea can occur with systemic exposure to sulfur mustard secondary to inhalation exposure. Persistent and bloody diarrhea may occur with severe systemic exposure as a result of damage to the gastrointestinal tract.

Blister formation resulting from exposure to sulfur mustard has been photographically documented in a number of cases; however, these photographs are often collected under ideal conditions that include appropriate wound treatment and support as well as thorough medical care. Indeed, most photographs of sulphur mustard blisters have been collected in a hospital setting. Not only did victims of the Jebel Marra attacks not receive appropriate medical care, but they often spent many days traversing difficult terrain to escape attacks. Blisters that formed from chemical exposure would likely not remain intact during this time and the opportunity for secondary infection is very high. Furthermore, photographs of these wounds could not be taken until many days or weeks after attacks because cameras are not readily available in this region. There is currently no report available regarding secondary infection of sulfur mustard blisters on dark skin tones, nor is there any information available regarding sulfur mustard wound progression without medical intervention, or how these wounds progress in extreme climates such as a mountainous region like Jebel Marra. So, comparisons between our photos and those included in reports of other attacks might be invalid. As a whole, however, our photographs and testimony do support exposure to vesicants based on ocular, respiratory, and dermal blistering effects.

Figure 2: Blisters on the face and head of a child. Significant swelling of the face including the eyes, lips, and cheeks is also visible.

Figure 3: Circular-shaped lesions around the buttocks and genital area. Swelling may be indicative of a secondary infection.

Evidence of Vomiting Agents

Nausea and vomiting, occurring immediately after exposure to the plumes from the blasts, was described in most victim and caretaker testimonies. Diarrhea was also a frequently described symptom, usually beginning the same day as exposure. While many chemicals can cause these symptoms, a specific class of chemical warfare agents, called vomiting agents, was designed to produce these symptoms. These agents were developed to serve as riot control agents, but have found utility as chemical warfare agents for incapacitating militias and other forces. Symptoms of exposure to these agents can cause eye irritation, sneezing, or irritation of the upper respiratory tract, and characteristic vomiting which can all develop within 30 seconds of exposure.[15] Historically, vomiting agents have been co-delivered with other chemical warfare agents. The gas formed by vomiting agents could permeate unsophisticated gas masks, prompting removal of the masks which then allowed for exposure to other chemical warfare agents.[16] Major symptoms of exposure to these agents, including nausea and vomiting, diarrhea and headache, are indicative of systemic exposure to the agent and these symptoms can last several days, or more post-exposure for severe exposures. Extreme exposures can ultimately result in death. The most immediate symptoms experienced by nearly all victims in Jebel Marra, including diarrhea and vomiting, are consistent with exposure to vomiting agents such as adamsite, diphenylchlorarsine, or diphenylcyanoarsine. However, long-term effects that were described by Jebel Marra victims, such as blister formation, persistent cough or lung infection, and skin necrosis, are not expected with acute exposure to vomiting agents. Therefore, it is possible that vomiting agents were mixed with other chemical warfare agents during some of these attacks.

Skin Infection or Chemical Exposure?

Many theories have been presented with alternate explanations for the cause of wounds observed by victims in the Jebel Marra attack. Certainly, skin infections appear to be a predominant explanation. Buruli ulcer, a chronic and necrotizing skin disease, is one possible explanation for some of the wounds that were reported. These ulcers are caused by Mycobacterium ulcerans infections and have been reported in Africa. However, the occurrence of these infections is relatively rare with just 2037 new cases reported worldwide according to the World Health Organization (WHO).[17] These infections generally start out as large swollen area or a plaque without pain or fever. Without treatment, the tissue begins to die and, if left untreated, the ulcer can consume large regions of the body. The progression of this disease is slow, with nodules forming over the course of weeks to months. Necrosis begins a few weeks later. In endemic areas, these ulcers can generally be identified by sight and by ruling out other conditions. We discounted Buruli ulcer as the initial cause of wound formation in the Jebel Marra cases because of the slow progression of the disease and because the wounds experienced by victims were described as painful, whereas Buruli ulcer is painless. Additionally, impetigo (a common bacterial skin infection that begins as red spots that eventually form blisters) has been suggested to have caused some of the dermatological findings in the Jebel Marra victims. While these blisters are not normally described as painful, they are often very itchy. Impetigo is also highly contagious, and it would be expected that caretakers would experience infections after caring for the wounded. Caretakers in Jebel Marra did not experience any skin disorders. This implies that the Jebel Marra victims did not have a contagious skin infection, such as impetigo.

A variety of other skin infections could present

15 K. Ganesan et al., "Chemical Warfare Agents," *Journal of Pharmacy & BioAllied Sciences* 2, no. 3 (September 2010): 166–178, http://www.jpbsonline.org/article.asp?issn=0975-7406;year=2010;volume=2;issue=3;spage=166;epage=178;aulast=Ganesan.

16 Marc J. Assael and Konstantinos E. Kakosimos, "Effects and Consequences Analysis," in *Fires, Explosions, and Toxic Gas Dispersions: Effects Calculation and Risk Analysis* (Boca Raton, FL: CRC Press, 2010). Print.

17 "Buruli ulcer," World Health Organization, n.d. Accessed February 27, 2017, http://www.who.int/mediacentre/factsheets/fs199/en.

similarly to the wounds of Jebel Marra victims. We are supportive of the analysis that these skin infections are secondary to the formation of a chemical wound, such as a blister. However, most skin infections develop much more slowly than the rate at which Jebel Marra victims' wounds developed, and the progression of skin infections is much different as well. We think it is critical that the clinical signs and symptoms of exposure be considered as a whole; almost all victims experienced vomiting and diarrhea nearly immediately after smoke exposure and wounds, which were described as blisters, developed. This progression cannot be adequately explained by skin infections.

Other Chemical Warfare Agents Potentially Used

In addition to sulfur mustard, we considered many other common chemical warfare agents when analyzing evidence, but these agents were not consistent with the testimonial and photographic evidence. For example, exposure to phosgene oxime exposure can immediately result in redness of the skin and also formation of red rings surrounding white, blanched skin. Exposure also produces intense itching of the affected skin. Ocular exposure results in symptoms similar to those observed, including pain, redness, and tearing. While many of these symptoms were described, the formation of a red ring was never mentioned in any testimony. Furthermore, phosgene oxime does not cause blisters that were frequently described by victims. Phosgene oxime has not been confirmed as the causative agent in any chemical weapon attack, thus data on these effects of phosgene oxime exposure are very limited. Based on the symptoms, phosgene oxime cannot be ruled out as a chemical used in the Jebel Marra attacks, but the history of this agent suggests that it is not likely to have been used.

White Phosphorus

White phosphorus has been frequently mentioned as an alternative potential cause for the wounds sustained in the Jebel Marra attacks, but we firmly believe there is no evidence for this view. White phosphorus is a highly reactive chemical that ignites when exposed to air, forming a dense white smoke.[18] This smoke contains various oxide forms of phosphorus that ultimately transform into highly corrosive chemicals such as phosphoric acid. Upon contact with skin, white phosphorus will burn continuously and deeply, reaching the bone if not stopped. These burns are usually described as producing white smoke on the skin and a "sizzling" sound. This type of burning and smoke formation was not described by any victim. Extinguishing white phosphorus on skin is very difficult and can continue despite dousing the affected skin with water. Burns from white phosphorus should be soaked in liquids and wrapped with wet cloths because drying out of residual embedded particles of white phosphorus can result in their re-ignition. Such prolonged burning results in thermal burns that can be very deep. Burns similar to those expected from direct contact with white phosphorus were not observed in victims of the Jebel Marra attacks. No victims described immediate burning of the skin or the presence of burning particles on skin that could not be extinguished. Furthermore, the pattern of wounds on victims is not consistent with those expected from white phosphorus. Common white phosphorus patterning can present like a "splatter" of burn marks on exposed areas or large swaths of skin can be burned depending on contact with the chemical and duration of this contact. Jebel Marra victims do have regions of dermal burns, but these do not appear like splatters. Some victims presented with large burned regions of skin, but these burns were not deep like those expected from white phosphorus and none of these victims described skin burning upon contact with chemicals or smoke during attacks. Therefore, exposure to white phosphorus is not likely to have caused the wounds on these victims.

Exposure to white phosphorus smoke, and not white phosphorus directly, has been frequently cited by others as a potential cause of the wounds sustained by Jebel Marra victims. White phosphorus smoke contains various byproducts of transformed white phosphorus including phosphoric acid which ultimately land in water and soil. Very few studies or reports are available on the effects of white phosphorus smoke

18 "White Phosphorus (WP)," GlobalSecurity.org, n.d. Accessed May 2, 2017, http://www.globalsecurity.org/military/systems/munitions/wp.htm.

in humans, but these limited studies suggest that respiratory effects, including coughing, throat irritation, respiratory distress, and chest tightness, would be expected.[19] The caustic agents in white phosphorus smoke are expected to cause ocular irritation including lacrimation and photosensitivity.[20] Death due to accidental or experimental exposure to white phosphorus smoke has not been reported. Additionally, no other information on gastrointestinal or dermal effects has been reported for white phosphorus smoke exposure. In contrast, severe gastrointestinal disturbances have been documented after oral ingestion of white phosphorus and, at minimum, can cause nausea, vomiting, and diarrhea. However, these ingestions are generally suicidal in nature and occur when fireworks containing white phosphorus are ingested. These effects have not been reported following exposure to white phosphorus smoke.

Although white phosphorus is a commonly used chemical obscurant during war, the presentation of victims exposed to either white phosphorus, or its smoke, is not consistent with victim presentation after the Jebel Marra attacks. White phosphorus itself can be excluded because burn patterning in victims does not match the patterning expected from white phosphorus, including deep burns and burns that developed immediately upon exposure to smoke. Furthermore, no victim descriptions provide any evidence indicating that white phosphorus burns occurred, such as descriptions of burning that could not be extinguished, burning of clothes, or burning immediately upon contact with smoke. White phosphorus smoke cannot be completely excluded, but does not account for all of the observed signs and symptoms of chemical exposure in victims of the Jebel Marra attacks. Exposure to white phosphorus smoke will affect the respiratory system which is consistent with victim experiences. However, nausea, vomiting, and diarrhea, primary symptoms experienced by victims, are not expected with exposure to white phosphorus smoke. Furthermore, the ocular symptoms of Jebel Marra victims are much more severe and persistent than would be expected with exposure to white phosphorus smoke.

Other Chemical Agents

Tear gas, commonly used as a riot control agent, could produce many of the symptoms and wounds that were exhibited by victims. However, the symptoms of exposure, such as coughing and ocular irritation, are expected to improve rapidly once victims are moved to fresh air. Conditions of victims in Jebel Marra did not improve after moving to areas with fresh air, but instead deteriorated, indicating immune suppression, which is a well-documented function of sulfur mustard.

Arsenic-containing pesticides can also produce coughing, ocular irritation, and blistering similar to what victims in Jebel Marra experienced. Furthermore, arsenic poisoning can result in a loss of appetite and weight loss, red or green coloring of urine, and a garlic-like odor on the breath, all of which were described in various testimonies. The amount of pesticide needed to cause the severity of symptoms observed in Jebel Marra would be very high and likely difficult, but not impossible, to deliver by bomb or rocket. So, exposure to arsenic-containing pesticides cannot be ruled out.

Finally, the trichothecene mycotoxin T-2, also known as "yellow rain," was considered because of its ability to cause blistering, vomiting, diarrhea and difficulty breathing. While this agent cannot be ruled out completely, it is unlikely the causative agent used in the Jebel Marra attacks because of the complexity of developing and weaponizing such agents. Furthermore, the scientific community has been unable to conclusively prove that T-2 has been used as a chemical weapon in the past; thus, it is unclear what symptoms would be expected after exposure to weaponized T-2.

Many victims described the smell of the gas used in the attacks as being unnatural or disgusting. Unfortunately, descriptions of chemical odors are generally not reliable for identification of chemical warfare agents due to variations in per-

19 "Toxicity of Military Smokes and Obscurants: Volume 2," National Research Council (US) Subcommittee on Military Smokes and Obscurants (Washington, DC: National Academies Press, 1999). Print.

20 Centers for Disease Control and Prevention, "WHITE PHOSPHORUS: Systemic Agent," Emergency Response Safety and Health Database, n.d. Accessed March 30, 2017, https://www.cdc.gov/niosh/ershdb/emergencyresponsecard_29750025.html.

ception of smell among individuals and the complexity of odors after a rocket blast. A combination of many odors would be expected in such an attack and could arise from a chemical warfare agent or any of its impurities along with explosive fuels and burning debris. For completeness, descriptions of odors provided in testimonies were considered during analysis of the Jebel Marra attacks. A description of a chlorine smell was described, but chlorine exposure can be ruled out in these cases based on symptoms. Likewise, an odor of rotten eggs was also described, and could be due to hydrogen sulfide, which is commonly associated with sewer gas and was used historically as a chemical warfare agent in World War I. Acute exposures can cause eye irritation and damage as well as coughing and nausea. Pulmonary edema, or fluid buildup in the lungs, is also expected and usually manifests as difficulty breathing. Exposure to high concentrations can cause skin irritation, respiratory arrest, and even death. Such high concentrations would be difficult to produce in an open air environment and would be more likely to occur in a confined space, such as a sewer. Though hydrogen sulfide cannot be definitively ruled out, it is unlikely the causative agent of the symptoms observed in Jebel Marra because of the high concentration needed to produce severe symptoms.

Possibility of Mixed Exposures

One complicating feature of the Jebel Marra attacks was that some signs and symptoms matched one chemical, while other signs and symptoms matched others. For example, caretakers frequently described that blood was present in the urine of victims. Likely representing kidney damage or infection, bloody urine can be caused by a multitude of chemicals, pathogens, and conditions. In this case, however, there were several reports of urine turning green, or a shade of red not associated with blood, which is consistent with exposure to arsenic and other chemicals. Additional evidence pointing to acute arsenic exposure includes bloody diarrhea, a high rate of spontaneous miscarriages, and developmental delays in children. Lewisite is an arsenic-containing chemical warfare agent that can cause the excretion of green or red urine. However, this information cannot be used to definitely prove that lewisite was used in these attacks. Likewise, most vomiting agents contain arsenic and could serve as the source of these symptoms. Based on the evidence that was gathered, exposures to multiple chemical warfare agents is quite possible. Immediate symptoms appear to have been produced by a vomiting agent, while long-term effects, including blister wounds that do not heal and persistent cough, appear to have been caused by a vesicant, such as sulfur mustard.

Combining Photographic and Testimonial Evidence

The analysis of individual data points, such as a single photograph or a single testimony, is not useful in the analysis of such complex cases. It was only through the analysis of photographic and testimonial evidence combined that a clearer picture of chemical exposure became evident. The immediate effects of exposure, including coughing, vomiting, and conjunctivitis, combined with the delayed effects of blistering and chronic cough, indicate that exposure to chemicals is the likely cause. Photographs showing circular lesions that appear to be from blisters, often infected, further support the conclusion that chemicals were used in these attacks. Identification of a specific class or agent used in the attacks is limited by a lack of photographic evidence immediately after wounds began to form, but delayed blistering is consistent with exposure to sulfur mustards. Furthermore, immediate effects, including conjunctivitis, are also consistent with sulfur mustard.

Photographic evidence was, at times, difficult to interpret and, indeed, alternate explanations have been provided regarding many of the photos included in the Amnesty International report. Many wounds appeared infected and many photographs showed what appeared to be necrosis of large portions of skin that could have resulted from chemical exposure or infection. First and foremost, none of the Jebel Marra photographs showed blisters that look like the traditional large blisters documented for confirmed sulfur mustard exposures. Nearly all available photographs of confirmed sulfur mustard wounds were taken in controlled settings, such as in hospitals or the field. Photographs are usually taken soon after exposure, and victims are almost always receiving appropriate medical care to stabilize blisters and prevent infection. In the areas of Jebel Marra where these chemical attacks occurred, medical facilities do not exist and treatment of wounds occurs in crude, unsanitary huts or out in the open. Additionally, cameras were not available in these regions immediately following attacks; thus, photographs of wounds collected for the report were taken weeks, or sometimes months, after the attack. Sulfur mustard wounds that have become infected over time from a lack of appropriate medical attention have not been documented, particularly on dark skin colors. Many of the victim photographs showed wounds that may have begun as clusters of blisters that subsequently became infected and inflamed. However, the circular nature of the wounds is very consistent with blister formation.

Conclusion

NGOs find themselves at considerable disadvantage compared to national governments when faced with evaluating evidence of alleged attacks using chemical weapons. Governments can use signals intelligence, human intelligence, measurements and signatures intelligence, and other means to gather data for analysis from the areas involved in alleged attacks.[21] Samples can be collected for analysis on-site and brought back for analysis in national laboratories designed specifically to handle samples containing Chemical Warfare Agents (CWAs). Such analyses provide the most definitive way to document the use of prohibited chemicals.

NGOs might choose to partner with private or academic laboratories to employ approved protocols for sample collection and analysis. But the problem of transporting samples across international borders and identifying laboratories to analyze samples that potentially contain CWAs remains a challenge. Excellent, easy to use, and affordable detectors designed for on-site analysis for CWAs are readily available within the United States. However, non-governmental parties are constrained by the International Traffic in Arms Regulations (ITAR),[22, 23] from readily acquiring these systems and deploying them in foreign countries, because these detectors often contain technology developed by and for the U.S. Department of Defense, and thus appear on the United States Munitions List.[24]

Despite these technical and regulatory disadvantages, investigations by NGOs of the alleged use of chemical weapons have played and will continue to play an important role in documenting violations of the CWC. Timely evaluations by NGOs can serve to trigger member state's use of national means to confirm these initial findings. When member states opt not to use or reveal the results of their own investigations, NGOs may provide the only public evaluation of allegations. It is important that NGOs continue to develop approaches to enhance the efficacy and reliability of their investigations.

Compared to previous work by NGOs on chemical weapons attacks, the Amnesty International investigation of the attacks in Jebel Marra, Darfur, discussed here was particularly challenging. We attempted to evaluate whether injuries to victims had been caused by exposure to chemicals or were simply a consequence of conventional weapons. This evaluation is particularly difficult when victims cannot be directly examined by medical personnel familiar with battlefield casualties, when there are no environmental and biological samples available for chemical analysis, and when even photographic evidence is collected long after the attack occurs. Nevertheless, we believe our careful analysis of the limited data from eyewitness accounts, combined with photographic evidence, has allowed us to conclude with some confidence that the injuries suffered by victims of these attacks were not caused by the effects of conventional munitions but could only be due to exposure to chemical agents.

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21 Robert M. Clark, "Perspectives on Intelligence Collection," *The Intelligencer* 20, no. 2 (Fall/Winter 2013): 47-53. Accessed January 16, 2017, https://www.afio.com/publications/CLARK%20Pages%20from%20AFIO_INTEL_FALLWINTER2013_Vol20_No2.pdf.

22 U.S. Department of State, "The International Traffic in Arms Regulations," Directorate of Defense Trade Controls, n.d. Accessed January 16, 2017, https://www.pmddtc.state.gov/regulations_laws/itar.html.

23 "What is ITAR?," Government Relations, n.d. Accessed January 16, 2017, http://gov-relations.com/itar.

24 "Part 121-The United States Munitions List," U.S. Government Publishing Office, May 3, 2017. Accessed January 16, 2017, http://www.ecfr.gov/cgi-bin/text-idx?node=pt22.1.121#se22.1.121_11.

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