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Systems Analysis of Past, Present, and Future Chemical Terrorism Scenarios

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Abstract

Throughout history, as new chemical threats arose, strategies for the defense against chemical attacks have also evolved. As a part of an Early Career Laboratory Directed Research and Development project, a systems analysis of past, present, and future chemical terrorism scenarios was performed to understand how the chemical threats and attack strategies change over time. For the analysis, the difficulty in executing chemical attack was evaluated within a framework of three major scenario elements. First, historical examples of chemical terrorism were examined to determine how the use of chemical threats, versus other weapons, contributed to the successful execution of the attack. Using the same framework, the future of chemical terrorism was assessed with respect to the impact of globalization and new technologies. Finally, the efficacy of the current defenses against contemporary chemical terrorism was considered briefly. The results of this analysis justify the need for continued diligence in chemical defense.

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CONTENTS

1. Introduction.....	7
2. Analysis Framework.....	7
3. Scenario Elements in Historical Chemical Attacks	9
a. Chlorine attacks	9
b. Sarin attacks.....	10
c. Cyanide attacks.....	11
4. Scenario Elements in future chemical Attacks	12
a. Agent.....	12
b. Dissemination	13
c. Target.....	13
5. Implications for Contemporary Chemical Scenarios.....	13
6. Options for Chemical Defense.....	14
7. Conclusion	15
8. References.....	16
9. Electronic Distribution.....	18

FIGURES

Figure 1. Schematic of the Chemical Defense Model.....	8
Figure 2. Chemical attack scenario elements.....	9

NOMENCLATURE

CBRN	Chemical, Biological, Radiological, and Nuclear
CSC	Chemical Supply Chain
CWA	Chemical Warfare Agent
CWC	Chemical Weapons Convention
IED	Improvised Explosive Device
IST	Inherently Safer Technology
TIC	Toxic Inhalation Chemical
WMD	Weapons of Mass Destruction
WWI	World War I

1. INTRODUCTION

In our nation's current homeland security strategy, the defense against chemical terrorism has been overshadowed by efforts to protect against biological and nuclear threats. These threats are often prioritized because of the greater potential public health consequences compared to chemical scenarios. However, consequence is only one component of risk. In a cornerstone paper by Kaplan and Garrick, the authors propose that risk is best understood as a set of triplets including scenario, probability and consequence.[2] Building on this insight, Wyss and coworkers recently developed a definition specifically for security risk which utilized "difficulty" rather than probability.[3] The modified security risk triplet – scenario, difficulty, and consequence – examines the how difficult it is for an adversary to execute a terrorism scenario in order to achieve their desired consequences. Therefore, while high consequences drive the risks of biological and nuclear terrorism, the low level of difficulty, or the ease of executing a chemical attack, may elevate the risk of chemical terrorism to levels of equal importance. In light of this, we must ask ourselves: Are we in need a renewed effort toward national chemical defense?

To begin to answer this question, a systems analysis approach was employed to reexamine the risk of chemical terrorism based on both difficulty and consequences of modern-day chemical scenarios. To inform this discussion, an analysis framework based on three major scenario elements was developed. Using the framework, a comparative, high-level analysis of the difficulty in executing chemical scenarios versus other weapons of mass destruction (WMD) scenarios was performed. Historical examples of chemical terrorism were examined to determine how the use of chemical threats, versus other weapons, contributed to the outcome of the attack. Subsequently, the future of chemical terrorism was evaluated based on an impact analysis of globalization and new technologies on each of the three scenario elements. Finally, the efficacy of the current defenses against contemporary chemical terrorism was considered briefly in order to justify the need for a continued diligence in chemical defense.

2. ANALYSIS FRAMEWORK

Chemical terrorism, or the use of toxic chemicals to kill, injure or otherwise negatively impact a target, may be driven by any number of adversary motivations. However, a terrorist's selection of chemical weapons over other types of weapons would be based on their resources (e.g., funding, manpower, technical capability) and their objectives for a specific attack. A scenario framework model was developed to describe an adversary's actions and decisions leading up to a chemical attack. The scenario framework is one aspect of a larger system of systems model of the chemical defense system (Figure 1). The larger system of systems model, which also includes a model of the defense architecture, can be used to investigate the interactions between the adversary and the defense in order to understand and predict the behavior of chemical terrorism.[1]

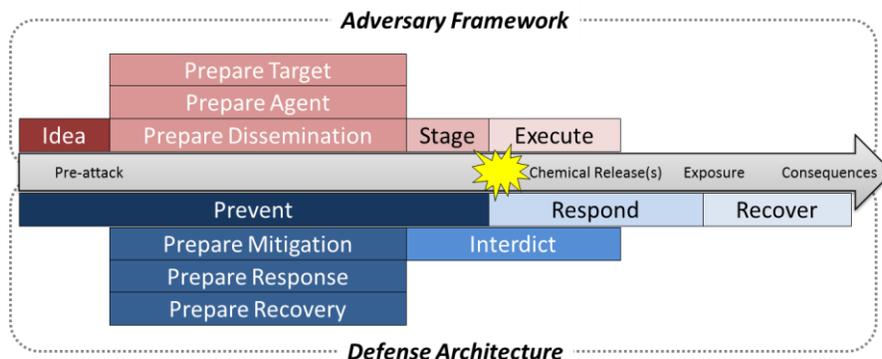


Figure 1. Schematic of the Chemical Defense Model.[1] An Adversary Scenario Framework and a Defense Architecture are modeled jointly in this system of systems model. The model is based on the scenario timeline (gray arrow) and includes all adversary and defense activities and decisions leading up to and following a chemical attack.

Within the adversary framework, a chemical attack scenario is characterized by three interrelated elements: the agent, the target, and the method of dissemination. An adversary will develop each of these scenario elements until they have shaped what they perceive to be a feasible plan for executing the attack. In preparing an attack, an adversary has many options for each scenario element; therefore countless number of chemical attack scenarios can potentially be devised. For many chemical agents, the time-to-effect for intoxication occurs on the order of minutes after exposure.[4] The rapid onset of symptoms places severe constraints on defense options for detection and response to chemical incidents, and is a key characteristic of chemical agents that distinguishes them biological agents and other WMD. A second key distinction between chemical agents and others is the degree to which hazardous chemicals are used for commercial applications. This characteristic subversively facilitates the preparation of the agent element for use in chemical attacks. Developing the agent element may involve activities such as buying, stealing and/or synthesizing chemicals, storing or stockpiling prepared chemical agents, developing formulations, testing the toxicity, etc.

Attack targets can be roughly categorized into four venue types: indoor, outdoor, food/beverage, and water supply. The chemical supply chain (CSC) is a special category of outdoor targets because the chemical agent for the attack is intrinsic to the target. To prepare for an attack on a specific target, an adversary may learn the schedule or operations of their target, identify vulnerabilities or ways to overcome security features, perform walk-throughs or test runs, and subsequently develop a procedure to execute an attack based on the information they have gathered. Finally, the dissemination method is similarly versatile and may be developed based on the properties of the chemical agent and target selected.

The efficacy of each element is dependent on the nature of the other two elements (Figure 2). A chemical agent's potential to cause severe toxicity depends on the route of exposure. Exposure via inhalation, ingestion and/or dermal is determined by the method of dissemination and the characteristics of target. The efficacy of the dissemination strategy is dependent on the physical properties of the chemical agent (i.e., volatility, solubility, etc.) and the fate and transport environment provided by the target. Conversely, the type of venue targeted in an attack

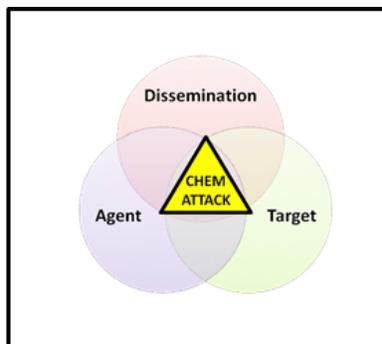


Figure 2. Chemical attack scenario elements. The agent, target and dissemination method are interdependent, and the three elements together determine the nature of a chemical scenario.

constrains how the agent and dissemination elements are implemented. This is especially true if the target is the CSC because the agent and the location are predetermined. The interdependences and the complex interactions between the chemical scenario elements, along with the numerous possible permutations of the elements, make chemical terrorism a challenging threat to defend against.

3. SCENARIO ELEMENTS IN HISTORICAL CHEMICAL ATTACKS

There is far more historical and contemporary precedent for the malicious use of chemical agents than for that of either biological^a or nuclear agents.[5] This includes the weaponization of chemicals for use in warfare, as well as the use of toxic chemicals to poison individuals or groups of people. In some cases it is difficult to distinguish between criminal behavior and chemical terrorism. This, in and of itself, is an indicator of the relative frequency of chemical threats compared to biological, radiological or nuclear threats. In this section, the scenario elements will be examined in several historical cases of chemical attacks.

a. Chlorine attacks

Precedent for the use of toxic chemicals to poison an adversary extends far back into history. However, a paradigm shift in the use of chemical weapons occurred in World War I when in 1915 German forces released chlorine against unprotected Allied soldiers from cylinders deployed along the front lines in Belgium resulting in thousands of casualties in a single attack.[6] The combat use of noxious gases in WWI precipitated development of protective equipment for military personnel, which, even in modern warfare, effectively mitigates the impact of chemical weapons against protected forces. However unprotected people and civilian populations are still vulnerable to the effects of these weapons. At present, the use of chemical weapons is prohibited under the Chemical Weapons Convention^b (CWC)[7], however, illicit chemical activities and the use of chemical weapons still occurs in many parts of the world. For example in 2007, a series of more than ten chlorine canister bombings were conducted by Al

^a The 2001 anthrax letters are a notable contemporary biological incident.

^b At the time this manuscript was written, there were 188 States Parties to the CWC and 7 non-member states. There were other international laws prior to the CWC that forbid the use of chemical weapons including the 1925 Geneva Protocol and the 1899 Hague Declaration (IV, 2).

Qaeda operatives against civilians and U.S. military in Iraq.[5, 8] Each of these incidents resulted in a handful of deaths (primarily resulting from the explosions) as well as a number of inhalation injuries from chlorine exposure in both military and civilian populations. Experts noted an evolution in the sophistication of these attacks such that the later incidents had improved dispersion of chlorine compared to the earlier attacks in which the explosion destroyed much of the chlorine.[9] Chemical attacks using chlorine are not isolated to the tumultuous Middle East. In 2011 an Arizona business man was found guilty on charges of the illegal use of a chemical weapon for his attack on disgruntled customers with a chlorine device^c. [10]

The agent element in each of these scenarios was chlorine, although the size of the attacks ranged from small-scale to very large. Chlorine is a dense gas that results in a persistent inhalation hazard when released. Chlorine is used globally as a disinfecting agent (e.g., in water supplies) and in the chemical industry as a precursor to other chlorinated products. The widespread use of chlorine increases the accessibility of the agent to rogue actors through either theft or purchase. Other toxic industrial chemicals (TICs) such as cyanides (see appendix for a discussion of historical cyanide incidents) and pesticides may be similarly accessible for malicious use in chemical attack scenarios. Furthermore, the CSC, or the system of infrastructure that supports the industrial distribution and use of TICs have also been targets of chemical attacks. For example, in one of the 2007 chlorine incidents in Iraq, a tanker truck carrying chlorine was targeted with explosives. In this type of the scenario, the agent and the target elements are one in the same. Three different methods of dissemination were employed in these examples. Dissemination of toxic gasses such as chlorine may be as easy as discharging a gas cylinder or can involve more complex methods such as the chlorine-encased improvised explosive device (IED) or even released from simple reactions of commercially available chlorinated products.

b. Sarin attacks

A recent and often-cited example of chemical terrorism is the 1995 sarin attacks in the Tokyo subway system^d perpetrated by the extremist group Aum Shinrikyo. The cult was responsible for a number of other chemical attacks against a total of 11 targets, including another attempted mass-murder sarin attack in the summer of 1994 targeted at the occupants of an apartment building in Matsumoto.^e While the execution of these attacks is intriguing, the effort to prepare for these attacks, including both successes and failures, provide significant insight into the feasibility of chemical terrorism. Many experts have evaluated the Aum's activities and motivations [11, 12] however, for this study only a few key findings on the logistics of preparing the chemical agent and the method of dissemination will be discussed.

^c The agent formulation and the dissemination device used in the AZ attack were not reported.

^d In the 1995 Tokyo Subway attacks, Aum cult members carried bags of liquid sarin onto five different trains during morning rush-hour where, at a coordinated time, the bags were punctured with sharpened umbrella tips. Sarin evaporated from the liquid puddles which resulted in the inhalation exposure for thousands of people. In addition, a couple members of the subway personnel suffered dermal exposure as they unknowingly tried to clean up the puddles. Ultimately, this scenario led to at least a dozen fatalities and upwards of 6,000 injuries.

^e In the 1994 Matsumoto attack, a plume of sarin was released from a delivery truck fitted with a vaporizing device. Although the truck was parked near the apartment complex, a shift in the wind misdirected the plume away from their intended target. The toxic release resulted in eight fatalities and approximately 200 injuries.

The agent scenario element was reasonably well-developed for these attack scenarios. Aum conducted a sizable and relatively successful chemical program, whereas their concurrent attempts to develop a viable biological program failed repeatedly. Experts agree that this is an important indicator of the accessibility of chemical agents over biological agents.[11] The chemical agents used in the Aum attacks were synthesized from commercially available precursors in laboratory facilities constructed specifically to support the chemical program. At the outset of the program, the synthesis was demonstrated by a cult member with formal training in chemistry; however, the large-scale production was led by those with limited chemistry knowledge. Post-incident analysis of the agents has indicated that the sarin products utilized in both the Matsumoto attack and the subway attacks were relatively impure (around 70% and 30% sarin, respectively). This is also an important finding because it demonstrates that, in spite of the significant impurities, the chemical agents acquired were still effective in the attacks, which would not be the case for attenuated biological agents. Acquisition of analytically pure chemical agents would have required more resources, manpower and technical expertise.

The method of dissemination was an element of continual weakness for Aum's chemical attack scenarios. The punctured bags of sarin in the subway attack caused only minimal dispersion of the agent, thereby achieving a fraction of the potential impact. Although the puddle release was a rudimentary delivery system, the coordinated release in distributed locations improved the efficacy of the overall dissemination method. During the Matsumoto attacks, the modified truck, which had been improved from previous designs, was an effective device for releasing significant amounts of vaporized sarin. However, difficulty directing the plume from their location caused the attackers to miss their target altogether. These examples allude to that challenge of dissemination with a goal of mass-casualties: it increases the complexity and therefore the difficulty to both accurately target and effectively expose a large population.

c. Cyanide attacks

Throughout history people have been using cyanides to poison individuals or specific groups of people.[13] A couple of relatively recent examples include an incident on New Year's Eve of 1994 in Tajikistan when at least nine soldiers and six civilians died, and 53 others were hospitalized, when they drank champagne laced with cyanide. The bottles of champagne were sold just outside of a military compound that housed members of the Russian peacekeeping force.[14] In a similar scenario, several packages of Tylenol were laced with cyanide in Chicago in 1982. Seven people died and \$100 million of product were recalled.[15] The perpetrators were not identified in either of these attacks, and it is still unclear if the Tylenol attack was politically motivated (some analysts argue that this is a requisite factor to be defined as a terrorist attack). There are several other reports of known terrorists who were in possession of cyanide who presumably had intent to employ it in an attack; however their planning activities were interdicted before the attacks were executed. Examples of these incidents include: the Alphabet Bomber[12], who had successfully executed a series of bombings in the Los Angeles area, was in possession of 25 pounds of sodium cyanide and other chemical agents and precursors; a religious cult called the Covenant, the Sword and the Arm of the Lord[12] were discovered to have a 30 gallon drum of potassium cyanide and plans to poison city water supplies; and finally a militia man from Texas was charged with possession of a chemical weapon when law enforcement found two pounds of sodium cyanide along with other materials and devices needed to disseminate the agent.[5] While some analysts argue that these do not represent scenarios of

significant impact and should therefore not be a priority for national chemical defense[16], the ease of initiation into cyanide attack preparation demonstrated by these and many other historical incidents should raise concern about the potential for multiple, small-scale attacks with cyanide agents.

4. SCENARIO ELEMENTS IN FUTURE CHEMICAL ATTACKS

Studies have shown that a well-executed chemical attack could potentially result in mass-casualties.[17-19] However, chemical scenarios are typically perceived to be of lesser concern for mass-destruction compared to biological and nuclear weapons. Past incidents indicate chemical terrorism attacks are relatively simple to carry out compared to more technically challenging scenarios involving biological and nuclear weapons. Most of these less-sophisticated historical attacks resulted in relatively few fatalities with large numbers of people suffering injuries due to exposure. Current trends in terrorism approaches indicate a shift toward executing multiple, smaller attacks to cause chaos, fear and eventually chronic weaknesses (i.e., an objective of “death by a thousand cuts”).[20] Therefore, the modest impact of a simple chemical attack coupled with the ease of access to chemical terrorism may point toward a potential increase in the use of chemical weapons in future terrorist attacks.

The future of chemical terrorism is changing in other ways, as well. New technologies in chemistry and several other technical fields (engineering, materials science, biology, etc.) have the potential to further increase the ease of executing successful chemical attacks.[21] Much attention has been given to the emerging biological threats with the exponential increase in new microbiological technologies.[22] The evolution of chemistry technologies and the intersection of biotechnology with emerging chemical terrorism arguably warrant equal concern and attention. Discussion in the following sections will focus on how each element of a chemical scenario may be impacted by novel technologies and globalization.

a. Agent

In the past, an adversary may have pursued TICs over traditional chemical weapon agents (CWAs) for their attack scenario, in spite of their lower toxicity, simply because of their apparent abundance and ease of access. However, with new synthetic methodologies and technologies, such as biocatalysis, micro-reactors, synthesis robots, and automated purification systems, CWAs and other highly toxic agents that were traditionally considered to be too synthetically challenging for the average terrorist to acquire may become more accessible agents. New technologies such as these are often further developed into commercially available equipment that can be operated by less sophisticated users for chemical industry applications. The chemical program of Aum Shinrikyo was noted to have purchased a “turn-key laboratory” of this type from Switzerland in their effort to scale up the synthesis of Sarin.[23] Accelerating progress in molecular discovery could also inadvertently lead to the development of more toxic chemical agents that would be of interest to terrorists. For examples, advances in pharmaceutical research and computational chemistry toward the optimization of molecular recognition, in combinatorial chemistry to build libraries of tens of thousands of new compounds, and in formulation chemistry for improvements in time-released and targeted drug delivery, could all potentially be misused.

b. Dissemination

As the manipulation of chemical agents becomes more facile, the ease of dissemination of the agent may also be improved. Advances in formulation chemistry related to adhesion, thermal stabilization, weather resistance, and solubility may be applied toward preserving the chemical agent during dissemination. Similarly, new foam and aerosol technologies developed for applications in agriculture, healthcare, and industry can be used to improve strategies for the dissemination of dermal and inhalation hazards. Finally, technology for automation and remote operational capabilities may enable an adversary to release a hazard more covertly or simultaneously in several locations, resulting in higher consequences and less likelihood to attribution.

c. Target

Most targets of a chemical attack, whether indoor, outdoor, food/agriculture, or water, can become more vulnerable with enhanced agent characteristics and dissemination methods. In lieu of a more complex agent or dissemination strategy, targeting the CSC is becoming a more feasible attack strategy. The CSC in our nation is expansive and increasingly includes foreign suppliers and consumers. With the new trend toward smaller chemical plants producing multiple chemical products, the CSC has grown such that there are now chemical plants and/or transportation routes for hazardous chemicals in every state of our nation, often passing through urban centers and major metropolitan areas. As a result, an adversary can target the CSC to release TICs in almost any location they are interested in. Furthermore, as more people and countries also have access to the new technologies employed in chemical industry, an adversary's access to these chemicals and capabilities also increases.

5. IMPLICATIONS FOR CONTEMPORARY CHEMICAL SCENARIOS

The threat of WMD based on chemical, biological, radiological, or nuclear (CBRN) agents continues to be of general concern for our nation's defense programs. Among these, chemical terrorism is a unique threat in many ways compared to other agents of terrorism. Chemical agents are relatively abundant, accessible and inexpensive. Hazardous chemicals that can be weaponized are found in commercially available disinfectants and fertilizers, and are a part of the fabrication processes for many of our household products. Residents of the U.S. live amid a vast network of chemical infrastructure comprised of hundreds of nation-wide chemical plants and transport systems (including truck, railcar, barge, and pipeline). While chemicals have become a part of everyday life and an important part of the economy, they can pose a great threat if they are misused. In comparison, there are aspects of biological and nuclear threats that are also dual-use, for example the commercial use of Botulinum toxin (Botox®) or nuclear reactors for power, respectively. However, as previous attacks have demonstrated, it is far easier for a rogue actor to acquire resources for chemical terrorism compared to an effort to acquire and process biological or nuclear materials.

Relatively low levels of technical expertise are required to prepare and execute a chemical attack compared to biological and nuclear terrorism.[11] Aside from the abundance of TICs, synthesis methods for other chemicals agents need only produce moderate yields and purity of an agent to be useful for an attack. A terrorist does not necessarily have to be able to mass produce an agent,

nor do they need to ensure long-term stability of that agent because even small amounts of agent may be effective in some scenarios. Similarly, even rudimentary dissemination strategies, such as discharging gas canisters or sabotaging the CSC, can have modest to severe impacts. With this low-tech level of entry into chemical attack activity, it is important that failed chemical attacks are not simply dismissed or chalked up to defense successes. In reality, failures in simple chemical attacks hold greater potential for lessons learned by the terrorist and his copy cats compared to failed attempts to develop other types of WMD attacks.

Finally, the rapid time-to-effect of many chemical agents, the dual-use nature of toxic chemicals, and breadth of possible chemical attack scenarios makes it difficult to develop a defense architecture with a centralized protection strategy. In contrast, the defense against nuclear terrorism is primarily focused on interdiction. Similarly, the primary focus of the biological defense architecture is on the first response element which strives for early warning detection and mitigation through medical countermeasures. To manage the multiple axes of influence between the chemical scenario elements, an end-to-end defense strategy against chemical terrorism is required. A comprehensive chemical defense architecture of this type would ideally be specific to chemical threats (i.e., not integrated with biological and nuclear defenses) and would incorporate elements from prevention and protection through response and recovery.

6. OPTIONS FOR CHEMICAL DEFENSE

Although there are several programs currently underway within the Department of Homeland Security to acquire capabilities and resources to protect against chemical threats, there are two general weaknesses in the current approach to chemical defense. First, protection against chemical threats is often coupled to other existing WMD defense architectures, especially with that of biological defense. As discussed in this report, applying the defense strategies derived from either the biological or the nuclear architecture would be ineffective for a large fraction of chemical incidents. Second, the integration of existing chemical defense resources and capabilities into cohesive defense architecture continues to be a challenge. Integration could be facilitated in part by developing a chemical-specific strategy but also by rigorously applying a systems engineering approach to developing a chemical defense architecture. For example, a person may be quick to reason that chemical detection is an effective tool for chemical defense. However, rather than purchasing the latest and greatest detector technologies based on this intuitive reasoning, a systems engineering approach would first characterize the threat, identify the defense needs, and define requirements for defense solutions before procuring new technologies. By using systems engineering, defense solutions are tied directly to a need, and are better integrated with one another into a defense architecture. In spite of shortcomings in current approaches, chemical defense is progressing in a few promising directions: 1) eradicating proliferation of chemical weapons from the CWC, and 2) leveraging chemical safety programs in industry for chemical security.

The CWC, which is marshaling a relatively successful effort to destroy existing chemical weapons and prohibit the production of new chemical weapons[7], continues to strive to address potential sources of future proliferation. Under request of the CWC Director-General, the Scientific Advisory Board identified a number of advances in science and technology that may be of interest in the next review of the CWC.[24] These topics include: the convergence of chemistry and biology, the accelerated discovery of chemicals, nanotechnology, technologies for

delivery systems, and production technologies. Addressing the national security concerns in these types of technical advances is no easy task; however efforts to do so will shift the posture of our defense from one of reflexive response measures to an anticipatory planning posture with the goal of being “a step ahead” of the terrorists next move.

Incidents of accidental chemical releases, including the release of Methyl Isocyanate at a Bayer plant in 2008[25], the series of toxic releases from a DuPont plant in 2010[26], and many other incidents, have led to a growing public awareness of issues related to chemical safety in industry and the CSC. A consumer push for safety and sustainability in the chemical industry has subsequently led several chemical companies to change their practices for how they handle chemicals and waste through the use of Inherently Safer Technologies (IST) and green chemistry. Many of the measures that minimize or eliminate the use of toxic chemicals in industry can also improve security in the CSC by reducing the amount of hazardous chemicals transported and stored around the country. While the chemical industry is adamantly against government mandates and regulations for IST[27], there are significant potential benefits to reaching a common ground where government efforts for chemical security and industry efforts for chemical safety can be mutually leveraged.

7. CONCLUSION

This paper reviewed the current dynamic state of chemical terrorism by assessing what we have learned from previous incidents of chemical terrorism as well as how globalization and the rapid evolution of technology may shape the future of chemical threats. Chemical terrorism is a unique threat compared to other WMD. Although chemical attacks are less likely to result in staggering numbers of fatalities compared to incidents of biological or nuclear terrorism, the threat is heightened by the dual-use nature of chemical agents and the ease of entry into illicit chemical activities. The author is in agreement with others who have argued that it is important to avoid overstating the threat by building a defense on worst-case scenarios.[16] However, as Bernstein *et al.* poignantly stated, “one need not view the threat as existential to be gravely concerned, and one need not engage in worst-case planning to make the case for substantial action across many fronts.”[28] Chemical weapons were historically and continue to be among the armory options for both domestic and international adversaries. As such, we have a responsibility to continue our development of a national defense strategy dedicated to the prevention and mitigation of acts of chemical terrorism.

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