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# *The Chemical Science of Warfare and Human Destruction*

Chemical technology can be used to produce chemical weapons; the close relationship of chemistry with the military is well known. Chemical warfare is the prime example of this deadly relationship: throughout recent history, collaboration between chemical engineers and the military has created potent compounds that can kill, injure, or incapacitate an enemy during time of conflict. It is unfortunate that science, which seeks to improve human life, is also contributing to destroy it.

**Early History**

Regrettably, our cultural history also contains the history of chemical weapons. Chemical warfare began with the poison arrows used by Neanderthals millions of years ago to kill first, animals for food and soon thereafter, to kill humans as well. An early reference to toxic weapons can be found in the Ramayana, ancient Sanskrit scriptures dating back to the 4$^{th}$ century B.C.[1]

The first use of gas warfare in the West dates back to the 5$^{th}$ century B.C. During the Peloponnesian War between Athens and Sparta, the Spartan army placed a lighted mixture of wood, pitch, and sulfur under the walls of an Athenian fortress to incapacitate the Athenians with the toxic smoke.

In the 15$^{th}$ century, Leonardo da Vinci proposed how chemical agents could be used in naval warfare. Da Vinci described a powder of sulfide of arsenic and verdigris, a copper carbonate, which could be thrown at small ships. However, it is unknown whether such tactics were utilized at the time.

**Regulation**

Today, the Chemical Weapons Convention (CWC) represents a global effort to eliminate chemical weapons. The CWC was ratified by the UN General Assembly in 1992 and is a multilateral arms control and non-proliferation treaty. Although full membership has not yet been achieved, the CWC functions to eliminate the development, stockpiling and use of chemical weapons. In addition, the CWC requires each party to destroy chemical weapons and their storage facilities. The CWC complements the 1925 Geneva Protocol, following WWI, which first prohibited the use of biological and chemical weapons; however, the Protocol did not forbid stockpiling, which only anticipated the later use of the weapons.

The CWC is important for regulating the activities of its member states and ensuring that these activites are in accordance with the purposes of the treaty. The United States is party to the Chemical Weapons Convention. Although the U.S. does not manufacture chemical weapons and is in the process of destroying its stockpile, it does produce, consume, export and import numerous dual-use toxic chemicals that are precursors to chemical weapons. This use of chemicals is within the mandate of the CWC, which does not prohibit production, processing, consumption, or trade of related chemicals for peaceful purposes.

The Biological Weapons Convention, ratified in 1975, underlines the importance of regulating not just chemical, but biological weapons as well. The Biological Weapons Convention (BWC) prohibits the development, production, and stockpiling of biological and toxin weapons, including microbial or biological agents whose use is not justified by “protective or other peaceful purposes.” Parties to the Convention are also banned from acquiring weapons or equipment designed for delivery of the agents in conflict. Perhaps the goals of the BWC are best echoed by Article X of the treaty:  “to encourage the peaceful use of biological science and technology." However, the BWC has no central authority to monitor compliance of party countries, which questions the ability of the BWC to control the use of biological agents.

Furthermore, there is no Nuclear Weapons Convention that prohibits the development and use of nuclear weapons. Without strict boundaries for the production and elimination of nuclear agents, it is clear that more effective cooperation is needed between the chemical sciences and government to ensure the safety of the world's citizens.

**Classification**

The Chemical Weapons Convention of 1997 proposed three classes of controlled chemical substances. The classification is based on the quantity of the chemical allowed for legitimate commercial use. Schedule 1 chemical weapons are only for research and chemical-weapon defense testing because they are most lethal of the chemical warfare agents. Nerve gas, ricin (a toxin extracted from castor beans that inhibits protein synthesis), lewisite (a vesicant and lung irritant), and mustard gas fall into this class. Schedule 2 weapons are chemicals that are primarily for small-scale industrial use, such as thiodyglycol, potentially used to manufacture sulfur-based blister agents such as mustard gas, a Schedule 1 substance that is hazardous as a vapor or contact agent. Schedule 3 concerns large-scale industrial use, apart from chemical weapons. For example, phosgene has been used as a chemical weapon but it is also used to produce a variety of industrial polymers such as polycarbonates. Similarly, triethanolamine is a precursor to detergents and toiletries although it can be used to make nitrogen mustard gas, a Schedule 1 substance that is similar to mustard gas, but is based on nitrogen rather than sulfur. Both nitrogen and sulfur mustard gases are compounds used in chemotherapy treatments.[2] Schedule 3 poses a problem because the majority of Schedule 3 substances have legitimate use in the production of common goods, making it difficult to distinguish between safe and lethal use.

**World War I**

The first and most notorious example of large-scale use of chemical weapons was during World War I that is sometimes called “the chemist’s war,” because military strategy on the battlefield involved new applications of chemistry and chemical engineering. The French army employed noxious chemicals such as tear gas and mustard gas. Tear gas is a non-specific term used for any chemical that causes temporary incapacitation via irritation of eyes or the respiratory system. Mustard gas, or sulfur mustard, is a vesicant chemical agent because it causes large blisters on the skin of the exposed and is mutagenic and carcinogenic. Sulfur mustard is an acid-forming compound; because it impedes cells from fixing oxygen, the cell must resort to anaerobic respiration, creating lactic acid in excess. In World War I, mustard gas was dispersed as an aerosol in a mix with other chemicals, giving its yellow color and distinct odor.

The use of chemical agents culminated in the Second Battle of Ypres in 1915 when the German army deployed 168 tons of chlorine gas to attack French, Canadian, and Algerian troops. Chlorine is a choking agent and a potent irritant. Chlorine gas, similar to mustard gas, is acid-forming, but is more pronounced in the respiratory system; at high concentrations it can cause death by asphyxiation. At Ypres, the chlorine gas easily dispersed through the air; the drawback to this military tactic was that both enemy and ally soldiers were exposed to the noxious chemical.

Phosgene gas, a vesicant agent, was developed as a result of growing demand for a chemical weapon that could be more easily controlled in times of conflict. Phosgene was developed by John Davy in 1812 but was first used as a chemical weapon by French forces in World War I, under the direction of French chemist Victor Grignard. Phosgene is synthesized as mixture of chlorine and carbon monoxide, and toxicity of the compound is due to the hydrogen chloride that is released upon hydrolysis. Phosgene gas is a more toxic weapon than chlorine gas but it takes over 24 hours for symptoms to develop in affected soldiers. In World War I, the combined effect of the use of chemical weapons was over 1.2 million casualties and 85,000 fatalities.

**World War II**

In the Second World War, although all major powers had stockpiled chemical weapons, their use was not prevalent, with the exception of Japan's use of mustard gas and lewisite in China. The Nazis manufactured chemical agents in large quantities, but large-scale use was not advocated for fear that enemies might also have access to the noxious compounds. Nonetheless, chemical troops were trained for chemical combat. Chemical agents were predominantly used during the Holocaust. In the extermination camps the Nazis employed a cyanide-based insecticide Zyklon B, first developed as a pesticide by Jewish Fritz Haber about 25 years earlier. The fatal agent was stored in airtight containers, but when exposed to air, released gaseous hydrogen cyanide.

World War II focused its attention on the development of potent nerve gases. Gerard Schrader, a chemist at the German chemical firm IG Farben, discovered the nerve agents tabun and sarin, today considered weapons of mass destruction. The nerve agents prevent the breakdown of the neurotransmitter acetylcholine in the victim's synapses, specialized cells of the nervous system. Sarin nerve gas is an extremely toxic organophosphate that disrupts the nervous system by inhibiting enzymes. The symptoms of intoxication from sarin nerve gas include seizures, loss of consciousness, and muscle twitching.

**Vietnam War**

Chemical agents were also used in the Vietnam War. The most controversial chemical weapon, napalm, was discovered in 1942 by an American chemist, Louis Fieser, who cooperated with the U.S. army to establish the use of napalm in bombs. The name napalm originates from its ingredients of "Naphtha" napthenic and "Palmitic." A jelly like material is formed as palmitic acids are added to a flammable substance like naphtha. When deployed, napalm creates severe burns and releases carbon monoxide that leads to suffocation. Napalm, extensively used by the United State in the Vietnam War, was delivered in the form of air-dropped incendiary bombs. Kim Phoc, a survivor of the napalm bombing of Vietnam, described the encounter with napalm as "the most terrible pain you can imagine. Water boils at 100 degrees Celsius. Napalm generates temperatures of 800 to 1,200 degrees Celsius."

Dow Chemicals, currently the second largest chemical manufacturer in the world, was the sole supplier of napalm to the U.S. military in the Vietnam War.  In addition to Napalm, the Dow Corporation developed Agent Orange, utilized despite the knowledge of its deleterious effects. Agent Orange is a defoliant that destroys vegetation by inducing rapid, uncontrollable growth in plants and contains dioxins, which are classified as halogenated organic compounds and known for their lipophilic (fat-liking) properties. The Agent causes long-term cancer effects and genetic damage. Between 1962 and 1971, U.S. planes deposited millions of gallons of the agent in Vietnam. An independent lawsuit was filed by Vietnam victims against companies that produced Agent Orange, including Dow Chemicals, but the case was dismissed in 2005 and no Vietnamese have received compensation.

**The Bhopal and Chernobyl Disasters**

The disastrous effects that result from the use of toxic chemicals are not restricted to times of war. More recently, the problem of storing and producing chemicals has led to graver consequences. The failure to properly manage noxious chemicals produced and stored in industrial plants can expose a large population to the harmful effects of these potent chemicals.

In 1984, in the city of Bhopal in India, a pesticide plant released 40 tonnes of methyl isocyanate gas, a highly toxic organic compound. The accident occurred when water entered a methyl isocyanate tank. The reaction led to an increase in temperature of over 200° C, overheating the tank and causing an explosion and release of toxic gas into the surroundings. Exposure to methyl isocyanate initially causes chest pain and coughing; over a period of 24 hours, victims experience pulmonary edema (the swelling and accumulation of fluid within the lungs), which leads to respiratory failure, cardiac arrest and death. As a result, 3,000 people were instantly killed in Bhopal and more than 120,000 still suffer from pollution caused by the accident.

The pesticide plant in Bhopal was operated by Union Carbide, one of the oldest chemical and polymer companies in the United States. Following the disaster, legal action by the U.S. and Indian government was taken against the company. A settlement was reached in 1989, and Union Carbide agreed to pay $470 million for damages caused by the explosion.[3]

Only two years later, the people in the city of Pripyat in the Ukraine awoke to sounds of explosions and fire. At the Chernobyl nuclear power plant, a reactor capable of producing 1 gigawatt of electric power suffered a steam explosion. As the lid of the reactor blew off due to pressure, the fatal mix of oxygen from the air and the high temperature of the reactor sparked a graphite fire. The explosion resulted in the release of radioactive materials and the radioactive fallout was spread throughout Europe and western Russia. About 5 percent of the radioactive core of the reactor was discharged. Noble gases such as krypton were released upon the first explosion, as was radioactive iodine. The outcome of Chernobyl was 56 immediate deaths due to radiation poisoning and over 4,000 deaths attributed to cancer amongst those living in the areas of highest radioactive fallout- Belarus, Ukraine, and Russia.

Both the Bhopal and Chernobyl disasters augmented adverse health effects, such as cancer and leukemia, among individuals exposed to radioactive fallout from the explosions. The affected areas witnessed a greater occurrence of diseases which impair the nervous system and liver. The environmental impact of the radioactive fallout was also severe, destroying plant and animal species.

**Ethical Implications**

Chemical warfare is a product of the union of chemistry and the military. Its potential is extremely powerful. But whose responsibility is it to control and enforce safe protocols to prevent noxious chemicals, often developed in large quantities for industrial purposes, from causing harm? Moreover, it is imperative to consider the ethical implications that arise with every new manufactured chemical agent that could potentially be used to destroy human life. What is the responsibility of the scientist? Should chemists continue to conduct research on a compound that will only have a negative impact on humans? The development also calls into question patriotism. Should scientists do all they can to protect their country by blindly following political agendas?

Many prominent scientists and public figures have collaborated to discuss the regulation of chemical weapons and preservation of world security. The efforts of these influential individuals are embodied by the Pugwash organization, which seeks to reduce the danger of armed conflict and create multilateral agreements. The Pugwash conferences, existing since 1957, bring together scientists, scholars, and policy makers that participate not as representatives of their countries, but instead as private individuals. Though the organization is not directly involved in policy making, the presence of government advisors at the conferences can greatly influence policy making in the respective countries; the Pugwash organization paved the way for the Nuclear Test-Ban Treaty of 1963 and the Non-Proliferation Treaty of 1968.

**Disposing of Dangerous Chemicals**

In today's global setting, chemical weapons pose a growing threat to the environment, health and well-being of the world's citizens. Chemical weapon proliferation is a threat us all, but one must also strictly control the destruction of chemical weapons. To eliminate stockpiles of chemical weapons, proper procedures must be followed to ensure the safe disposal of chemicals used to make lethal substances.

First, there are political measures that must be resolved. In the United States, the responsibility of chemical disposal rests with the Department of Defense and its contractors, who possess most of the money and power. Disposal activity is also regulated by Congress. Federal agencies such as the National Academy of Sciences' National Research Council and the U.S. Environmental Protection Agency oversee the disposal programs. Conflicting interest and a lack of consensus among the differing powers has often delayed action on the issue at stake.

There is a dire need for quick and efficient disposal of chemical weapon stockpile that can potentially leak chemical contents as it ages. Historically, chemical weapons were disposed by land burial, sea dumping, detonation and open-pit burning. The procedures may have eliminated the problem initially, but the disposal also had a devastating impact on human health and the environment. Unused chemical weapons from World War I, for example, were disposed of in the Baltic Sea. The salinity of the sea caused corrosion of shell casings and leakage of mustard gas from the containers. The mustard debris then washed onto shore as a solid that even in this form caused severe contact burns.

In 2003, the U.S. Army created the Chemical Materials Agency assigned with the task of safe storage and elimination of aging chemical weapons. Currently, there are nine stockpile locations in the U.S. and original plans to build incineration facilities are still under progress, with only four facilities containing operational incinerators to eliminate chemical weapons.

Incineration involves the combustion of organic materials but is a time-consuming and expensive method. Pentagon reports estimate that the cost for eliminating all stockpiles has increased from $2 billion in 1986 to $32 billion today. Furthermore, there are concerns over the health effects of dioxin emissions from incinerators, the dioxin a suspected human carcinogen. The incinerators also emit small amounts of heavy metals, such as arsenic, mercury, and lead, which are toxic even in small levels.

The U.S. Army created the Alternative Technologies and Approaches Project to evaluate the efficiency of different methods of chemical disposal. Research has led to the development of neutralization, a disposal technology that converts chemical agents into byproducts that can be disposed of easily. Neutralization uses alkalis and oxidants to reduce the toxicity of the chemical agent, which can then be safely disposed as hazardous laboratory waste.[4]

**Conclusion**

The regulation of chemical weapons requires greater cooperation within the international community. Undoubtedly, proper management will involve the elimination of existing chemical weapons and strict monitoring of chemicals potentially used for manufacturing of chemical weapons in order to ensure the health of all human beings. As Jayantha Dhanapala, Under-

Secretary-General for Disarmament Affairs for the United Nations stated, chemical weapons are "indiscriminately lethal. They recognize no difference between tanks and ambulances, between the old and the young, between the invalid and the healthy, or between man and woman, mother and child, even plant and animal." One does not want to limit scientists in their research, but it is up to both scientists and politicians to apply the chemical sciences toward global good.

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[1] The Ramayana describes a war between Rama, prince of India, and Ravana, ruler of Sri Lanka, the villain of the story. Rama was offered a new weapon that could destroy the entire race of the enemy, but Rama responded that such a weapon could not be used because destruction in such large numbers was forbidden by the ancient laws of war.

[2] The mechanism of action of nitrogen and sulfur mustard involves the intermediate of the molecule binding to a DNA strand, and the alkylation destroys the infected cell. Thus one can see its effectiveness in chemotherapy treatments.

[3] Controversies following the disaster heightened in 1994 when Dow Chemicals purchased Union Carbide and claimed that previous settlement payments made by Union Carbide fulfill the financial responsibility to the victims, and thus no money was to be allotted from Dow Chemicals. In addition, there were several reports released by Union Carbide claiming that the disaster was instigated by a plant worker who purposely connected a water hose to the tank.

[4] U.S. stockpile contains agents composed of carbon, hydrogen, oxygen, fluorine, chlorine, phosphorous, and sulfur. Low- or high-temperature oxidation processes could be used to breakdown of agents. The temperature processes oxidize carbon atoms to carbon dioxide ($CO_2$) gas which could then be incorporated in a salt such as calcium carbonate. Elements such as fluorine, chlorine, and phosphorous would be converted to their acidic or oxidized forms, HF, HCl, $P_2O_5$. Soluble salts require disposal in hazardous waste site to prevent leaching into groundwater.