SECTION IV

CHEMICAL WEAPONS TECHNOLOGY

SECTION 4—CHEMICAL WEAPONS TECHNOLOGY

Scope

Highlights

- Chemical weapons (CW) are relatively inexpensive to produce.
- CW can affect opposing forces without damaging infrastructure.
- CW can be psychologically devastating.
- Blister agents create casualties requiring attention and inhibiting force efficiency.
- Defensive measures can be taken to negate the effect of CW.
- Donning of protective gear reduces combat efficiency of troops.
- Key to employment is dissemination and dispersion of agents.
- CW are highly susceptible to environmental effects (temperature, winds).
- Offensive use of CW complicates command and control and logistics problems.

BACKGROUND

Chemical weapons are defined as weapons using the toxic properties of chemical substances rather than their explosive properties to produce physical or physiological effects on an enemy. Although instances of what might be styled as chemical weapons date to antiquity, much of the lore of chemical weapons as viewed today has its origins in World War I. During that conflict "gas" (actually an aerosol or vapor) was used effectively on numerous occasions by both sides to alter the outcome of battles. A significant number of battlefield casualties were sustained. The Geneva Protocol, prohibiting use of chemical weapons in warfare, was signed in 1925. Several nations, the United States included, signed with a reservation forswearing only the first use of the weapons and reserved the right to retaliate in kind if chemical weapons were used against them. (Note: the United States did not ratify the Protocol until 1975). Chemical weapons were employed in the intervening period by Italy (in Ethiopia) and Japan (in Manchuria and China). Both nations were signatories to the Geneva Convention. Chemical weapons were never deliberately employed by the Allies or the Axis during World War II, despite the accumulation of enormous stockpiles by both sides. Instances of employment of chemical weapons in the local wars since then are arguable, although they were definitely used in the Iran-Iraq conflict of 1982–87. In January of 1993, a lengthy and detailed Chemical Weapons Convention (CWC) was signed in Paris by many countries. Unlike the Geneva Convention's single paragraph prohibition, the CWC attempts to define the prohibited substances, including their effects, and to establish enforcement mechanisms. In addition to banning CW use, the CWC bans the development, production, stockpiling, and transfer of chemical weapons.

The CWC obliges a state party to destroy chemical weapons under its possession, jurisdiction, and control; to destroy all CW it abandoned in the territory of another state party; and to destroy CW production facilities under its jurisdiction or control. On April 29, 1997, the CWC entered into force, thereby putting in place a detailed and intrusive declaration and verification regime. Russia possesses the largest acknowledged stockpile of chemical weapons and may have difficulty adhering to the CWC's destruction reuirements because of economic difficulties.

Development of chemical weapons in World War I was predominantly the adaptation of a chemical "fill" to a standard munition. The chemicals were commercial chemicals or variants. Their properties were, for the most part, well known. The Germans simply opened canisters of chlorine and let the prevailing winds do the dissemination. Shortly thereafter the French put phosgene in a projectile and this method became the principal means of delivery. In July 1917, the Germans employed mustard shells for the first time and simultaneously attempted to use a solid particulate emetic, diphenyl chloroarsine, as a mask breaker. Mustard, an insidious material, penetrates leather and fabrics and inflicts painful burns on the skin. These two themes, along with significant increases in toxicity, represent a large segment of the research and development of chemical weapons that nations have pursued over the years. There is first the concept of agents that attack the body through the skin, preferably also through clothing, and more preferably through protective clothing. Along with that concept is the idea of penetrating or "breaking" the protective mask so that it no longer offers protection for the respiratory system. Increasing the toxicity of the chemical agent used would theoretically lower the amounts required to produce a battlefield effect. Unless this increase is significant, however, it can be masked by the inefficiencies of disseminating the agent. Consequently, later development has focused on the methods for delivering the agent efficiently to the target.

The chemicals employed before World War II can be styled as the **"classic" chemical weapons**. They are relatively simple substances, most of which were either common industrial chemicals or their derivatives. An example is phosgene, a *choking agent* (irritates the eyes and respiratory tract). Phosgene is important in industry as a chlorinating material. A second example is hydrogen cyanide, a so-called *blood agent* (prevents transfer of oxygen to the tissues), now used worldwide in the manufacture of acrylic polymers. The industrial application of many of the classic chemical agents is recognized by the CWC and they are included on a schedule wherein few restrictions apply. They would be only marginally useful in modern warfare and generally only against an unsophisticated opponent. Moreover, large quantities would be required to produce militarily significant effects, thus complicating logistics.

Blister agents or **vesicants** are an exception to the limited utility of classic agents. Although these materials have a relatively low lethality, they are effective casualty agents that inflict painful burns and blisters requiring medical attention even at low doses. The classic mustard is the most popular among proliferant nations since it is relatively easy to make. Mustard is generally referred to as the "king" of agents because of its ease of production, low cost, predictable properties, persistence, and ability to cause resource-devouring casualties rather than fatalities. Its insidious nature is both an advantage and a disadvantage. Mustard on the skin causes no immediate sensation and symptoms normally do not appear until several hours after exposure. At incapacitating levels this may be as long as 12 hours. (Contrary to the normal expectation, horrible fatalities occurred in the Iran-Iraq War because Iranian soldiers, feeling no effects, continued to wear mustard soaked clothing and inhale its fumes.)

To produce immediate effects, an arsenical vesicant known as lewisite was developed in the United States. Much of the former Soviet Union vesicant stocks were mixtures of lewisite and sulfur mustard.

Between the world wars the development of chemical weapons included adaptation to aircraft delivery (bombs) and exploitation of lewisite, since the more potent mustard was, from a battlefield perspective, slow in producing casualties. Independent experiments in several countries led them to consider/adopt mixtures of mustard and lewisite as fills for chemical munitions.

Nerve gases, or anticholinesterase agents, were discovered by the Germans in the 1930's and developed during World War II. In 1936 during studies of possible pesticides, the German chemist Gerhard Schrader discovered what he called "tabun" or GA. Two years later Schrader discovered the even more toxic "sarin" or GB. These compounds are orders of magnitude more toxic than those used in World War I and thus represent the significant toxicity increase that changed the concept of employment. Fortunately for the Allies, the Germans never exploited their technological advantage, although they did produce a large number of tabun-filled munitions.

Nerve gases are liquids, not gases, which block an enzyme (acetylcholinesterase) that is necessary for functions of the central nervous system. Similar in action to many pesticides, they are lethal in much lower quantities than classic agents. The nerve gases are effective when inhaled or when absorbed by the skin (percutaneous), or both, although there are differences in effectiveness. In general, the lower the material's volatility (and hence its inhalation threat) the greater its percutaneous toxicity. Nerve agents are generally divided rather arbitrarily into G- and V-agents, although there are numerous structural variants that are potent cholinesterase inhibitors. Nerve agents known to date to have been produced for chemical warfare purposes are all organophosphorus compounds and are liquids at room temperature.

The Italians, Hungarians, Japanese, French, English, Russians, and Americans, as well as the Germans, all perfected mustard, phosgene, and similar agents during World War II. Although never used in the conflict, these nations amassed such huge quantities of chemical munitions that their disposal presented a practical problem, one that would be virtually insurmountable in today's more environmentally conscious world. In those more naive times, however, the munitions simply found their way to the bottoms of almost all the world's oceans in the holds of expendable ships.

After World War II the victors took an interest in exploiting the potential of the remarkably potent "nerve" agents. The British, in particular, had captured small stocks of sarin (GB) and set about investigating its potential. The Soviets removed the Germans' GB production plant to the Soviet Union. GB turned out to be perhaps the best of the respiratory agents, being volatile as well as exceedingly toxic. The United States designed a cluster bomb to exploit the characteristics of GB and followed this with a litany of adaptations of munitions. Artillery rockets were produced as were bombs, projectiles, and spray tanks. Many of these used the basic design of high-explosive weapons and simply changed the fill to GB. In the instance of the spray tank, it was necessary to use a polymeric thickening material so that the liquid would form large droplets and not evaporate before it reached the ground. The French, British, and Canadians all built small-scale facilities to produce the GB for testing. The United States, however, entered into full-scale production of GB, as did the Russians just a little later. The Russians also produced soman (GD), an agent the U.S. developers had decided to forswear because of its properties of being refractory to treatment above a single lethal dose.

In the late 1950's, UK scientists discovered another category of nerve agents, the V-agents. These were particularly interesting in that most of them were very effective percutaneously and represented an effective way to circumvent the ubiquitous gas mask. The United States and the UK pursued a form of V-agent called VX, although they produced it by entirely different processes. The Russians exploited another structural analog that proved more adaptable to their industrial processes.

The 1960's saw continued development in nonlethal agents, or riot control agents, first used in World War I. These materials, most notably CS, are strong irritants of the mucous membranes with very high safety ratios. The letters "CS" are code letters for a solid powder classified as a riot-control agent (O-chlorobenzylmalonitrile). This

compound is a highly effective irritant of the mucous membranes with an exceedingly high safety ratio (~63,000). The purpose of CS and similar materials is temporary incapacitation without permanent harm. CS was developed and first used by the UK. It was quickly adopted and used extensively by the United States and since has been produced and employed by many nations. CS is a solid at room temperature and presents a problem for effective dissemination in useful particle sizes. Particulate CS, like most solids, tends to develop an electrostatic charge which causes the particles to agglomerate into larger particles. Much development effort during the 1960's was spent on finding effective dissemination techniques.

The work on particulate CS could be extrapolated to another type of chemical agent that was of extreme interest in the 1960's: **incapacitating agents**. These were initially seen by some as a panacea to make warfare safe and humane. Thousands of potential compounds were screened, obtained from government sources in the United States and from commercial pharmaceutical companies around the world. Although there were several promising materials, primarily mental incapacitants, only BZ was ever standardized.

The problem of incapacitants, or incapacitating agents, is complex. The use of incapacitants in warfare is considered to be prohibited by the Chemical Weapons Convention even though only a single agent, BZ (3-Quinuclidinyl benzilate), and its immediate precursors are included as listed compounds (Schedule 2) in that Treaty. In retrospect, while BZ was the only incapacitating agent formally accepted (i.e., type classified) by the United States, it was a poor choice and is now obsolete. It remained in U.S. stocks for only a short period of time. The substance is a mental rather than a physical incapacitant with long-onset time and unpredictable symptoms. The victim becomes confused and is likely to be incapable of acting decisively. The confusion, however, may not be readily apparent. The duration of action is long, about 48 hours, making prisoner management difficult. There are, moreover, hundreds of compounds more potent, faster acting, and with shorter duration of effect. Mental incapacitants are predominantly glycolates, whereas some of the more potent candidates for physical incapacitants have come from research on improved anesthetics. Indeed, almost all potential incapacitants are byproducts of the pharmaceutical industry and have legitimate pharmaceutical uses. The defining technologies for such incapacitating weapons, then, are the production of a physiologically effective compound in greater than practical pharmaceutical quantities and incorporation of the material in weapons. It is probable that the physical state of an incapacitant will be a particulate solid and that the practical route for effective use is by inhalation.

Binary chemical weapons use toxic chemicals produced by mixing two compounds immediately before or during use. Binary weapons do not necessarily employ new toxic chemicals. In U.S. parlance, relatively innocuous precursors were stored separately and reacted to form the toxic chemical agent en route to the target. In principle, the binary concept could also be used to produce highly lethal but unstable compounds or mixtures of compounds unsuitable for long-term storage. The U.S. type classified and produced a GB (sarin) binary nerve agent weapon, the M687 projectile (a 155-mm artillery shell), and was in the late stages of development of two other binary weapons when its offensive CW program was terminated. The Russians have been publicly accused by dissidents within their own agencies of developing new binary agents, and the Iraqis are known to have constructed binary bombs and missile warheads, albeit with crude manual mixing of the reactants.

Other possibilities for chemical agents include toxins and allergens which also have been, at times, considered biological agents. Although not living organisms themselves, these materials are usually products of living organisms with complex molecular structures. A wide variety of toxins with an equally broad spectrum of chemical, physical, and physiological properties exists. The CWC attempts to avoid the complexity by listing only two toxins in its list of substances for verification. They are ricin, a byproduct of castor bean extraction, and saxitoxin, a shellfish poison. Given the large number of potential toxins, these would appear to be place holders to permit the inclusion of any toxin if deemed necessary at a future date.

Until the recent attempts at terrorism by the Japanese cult Aum Shinrikyo, virtually all uses of chemical weapons have been as tactical weapons by nations. These have ranged from attempts to break the stalemate in World War I to the recent use by Iraq to blunt Iranian human wave attacks in the Iran-Iraq War (1982–87). Chemical weapons were not employed by the major protagonists in World War II. Between World Wars I and II, two signatories of the Geneva Protocol (Italy and Japan) employed chemical weapons. Typically, nations have employed them against unprotected targets and not against an equally well-armed nation; chemical weapons are therefore arguably an example of mutual deterrence. Although there have been charges of chemical weapon use in virtually every conflict in recent decades, most have not been substantiated by clinical or physical evidence.

The growth of chemical agent technology development that spurred production is illustrated in Figure 4.0-1. Chemical agents used initially in World War I were industrial compounds adapted for weapons use. As the war continued, more compounds were screened and specialized agents, particularly sulfur mustard, came to the fore. After the war, research continued at a slow but steady pace, with the major breakthrough being the German discovery of the nerve gases in the mid 1930's. Agent technology accelerated again in the 1950's with the British discovery of the V-agents. The 1960's featured extensive work and discovery in incapacitants and riot control agents as well as the early work on binary agents. If the dissidents of the Russian chemical program are to be believed, major advances are continuing.

In the lethal chemical arena a development effort that spread out over three decades was the concept of binary agent employment. This concept entailed the creation of highly efficient yet simple reaction schemes that could be used to create toxic agents from non-toxic ingredients in the weapon en route to the target. The United States

developed three different binary munitions, a GB projectile (a 155-mm artillery shell), an aerial bomb producing VX, and a medium-range missile warhead (for the MLRS) containing an intermediate volatility agent. Iraq made a crude attempt to exploit binary systems in the Gulf War, but none were actually deployed.

The Russian Army apparently quashed early attempts to develop binary agents by its technicians, although public revelations in 1995 by scientist Vil Mirzayanov and in 1996 by a former head of the Russian demilitarization program indicate recent Russian development of binary systems for new and novel classes of nerve agents.

An historical perspective of the growth of dissemination technology in comparison to agent technology also can be seen in Figure 4.0-1. Dissemination technology into the 1950's consisted mainly of the use of an explosive burster in adapted shells and iron bombs. During that time the concept of submunitions for better agent dispersal (e.g., missile warheads such as the Sergeant) and spray tanks (e.g., the Aero 14B) evolved and led to more uniform dissemination. These were followed in the mid-1960's and 1970's by concepts of thermal dissemination and aerodynamic breakup, as well as rheological techniques of particle size control in the 1990's.

Despite the importance of detection, the major technological advances for detection, identification, and warning are relatively recent. Initially, detectors were papers impregnated with a dye that underwent a color change when exposed to a chemical agent. By World War II, air-sampling tubes filled with liquids that changed color on exposure were available, as well as rather crude wet chemical point detectors. The advent of the nerve gases after World War II led to the development of sensitive enzyme detection techniques and point detection alarms. The latter were based on wet chemistry and required extensive servicing. The recent advances in microprocessing and fieldable instrumentation techniques have made remote and area sensing of chemical agents feasible.

A major advance in individual physical protection occurred very early with the development of the activated charcoal filtered gas mask. Many incremental improvements to aid in effectiveness against particular agents and to add to communication and creature comforts followed. Impregnated clothing for protection against percutaneous poisoning was another rather early development which continues to be improved incrementally by increasing protection factors and wearability.

OVERVIEW

This section addresses technologies that would enable a country to develop both offensive and defensive chemical weapons capability. The United States has forsworn the offensive use of chemical weapons and is a party to the Chemical Weapons Convention. Therefore, technologies for offensive military operations are not of interest except to maintain an appreciation for others' potential and to continue to develop a robust defense against them. References to offensive operations and technologies are included to ensure that there is an understanding of what is required to develop, integrate, and employ chemical weapons.

There are a number of reasons for a country to pursue the development of chemical weapons. Chemical weapons are relatively inexpensive to produce. Many standard munitions can be modified and filled with toxic chemicals. A chemical attack (or even a credible threat of a chemical offensive) can reduce the efficiency of an opposing force by making it take precautionary steps (donning protective suits, entering shelters, etc.) or diverting its attention to defensive measures. Casualties incurred can burden a country's medical resources. Unlike conventional weapons, chemical munitions, for the most part, injure or kill people while leaving the surrounding infrastructure intact. Moreover, because of their unconventional nature, chemical weapons can be psychologically devastating for a force being attacked.

Military forces that contemplate CW employment have many things to consider. The use of chemical weapons runs counter to the global norm and is apt to engender strong denunciation by third parties and retaliation by the nation attacked. There are significant operational hurdles. Logistics, training, and command and control are complicated by the possible employment of chemical munitions. Care must be taken to prevent one's own force from bearing the brunt of an attack. A properly defended force might be slowed but will not be stopped. Although the "cost" of CW employment could be high in terms of the above factors, the "benefit" of degrading an adversary's performance and the psychological affect might be deemed sufficient to offset the cost.

This section on **Chemical Weapons Technologies** contains four subsections. **Chemical Material Production** addresses technologies for producing toxic chemical agents that could be used in chemical weapons. Those that require special expertise are covered in more detail than those available through standard industrial processes. **Dissemination, Dispersion, and Weapons Testing** addresses those technologies that a proliferant could use to disperse toxic chemicals and ensure the viability of its dissemination systems. Also addressed are **Detection, Warning, and Identification** technologies that enable forces to detect and identify toxic agents and provide warning to minimize the threat. The last subsection, **Chemical Defense Systems,** discusses those systems that provide protection from the effects of chemical weapons.

RATIONALE

A number of technologies are required to develop, integrate, and employ chemical weapons. Although many of these technologies are old and available in the open literature, successful employment entails more than simply producing toxic chemicals. Technologies used for dissemination and dispersion are perhaps the most important. The myriad technologies for offensive use are included in this section to provide the reader an appreciation of the requirements to develop chemical weapons and an understanding of where offensive breakthroughs might occur, even though the United States

has renounced the capability. Technologies needed to detect the use of toxic chemicals and provide protection are essential to all countries. Even proliferants that employ chemical weapons require some type of detection and protection capability.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 4.0-2)

Starting in World War I, a number of countries have employed chemical weapons. After false starts by others, the Germans finally employed chlorine successfully at Ypres, Belgium, in 1915. Other WWI use included phosgene and chloropicrin in 1916 by the British, and mustard in 1917 by Germany. Lewisite was developed in 1918, too late to be used in WWI.

Between the world wars, Japan began research on chemical weapons and began production in the late 1920's. The Italians used mustard in Ethiopia in 1935–36. Although Allied and Axis nations produced and stockpiled chemical weapons, they were not used during World War II. Egypt employed mustard and probably G-agent in Yemen in the 1960's. Both sides relied on CW during the Iran-Iraq conflict. The Iraqis used mustard, tabun, and sarin from 1982–87 and were prepared to do so in the Gulf War. Libya dropped chemical agents from a transport aircraft against Chadian Troops in 1987.

Many nations have become States Parties to the CWC and can be expected to adhere to their commitments not to develop chemical weapons. Others will not sign or may abrogate their commitments. Any nation with a sophisticated chemical industry has the potential to produce chemical weapons, although nerve agents require a greater amount of expertise than classical agents and vesicants. Having the potential, however, does not indicate intent.

Subnational groups, both independent and state-sponsored, could produce or purchase toxic chemicals or possibly chemical warfare agents to threaten a civilian populace. Since civilians are poorly prepared for attacks by toxic materials, consequences of a successful attack could be severe. Governments are increasingly concerned about the use of toxic chemicals in light of the Aum Shinrikyo attack in Tokyo but thus far have been unable to come to grips with the complexity of the problem. The armed forces of many nations have some type of detection equipment and protection gear, although there are wide variations in their quantity and capability.

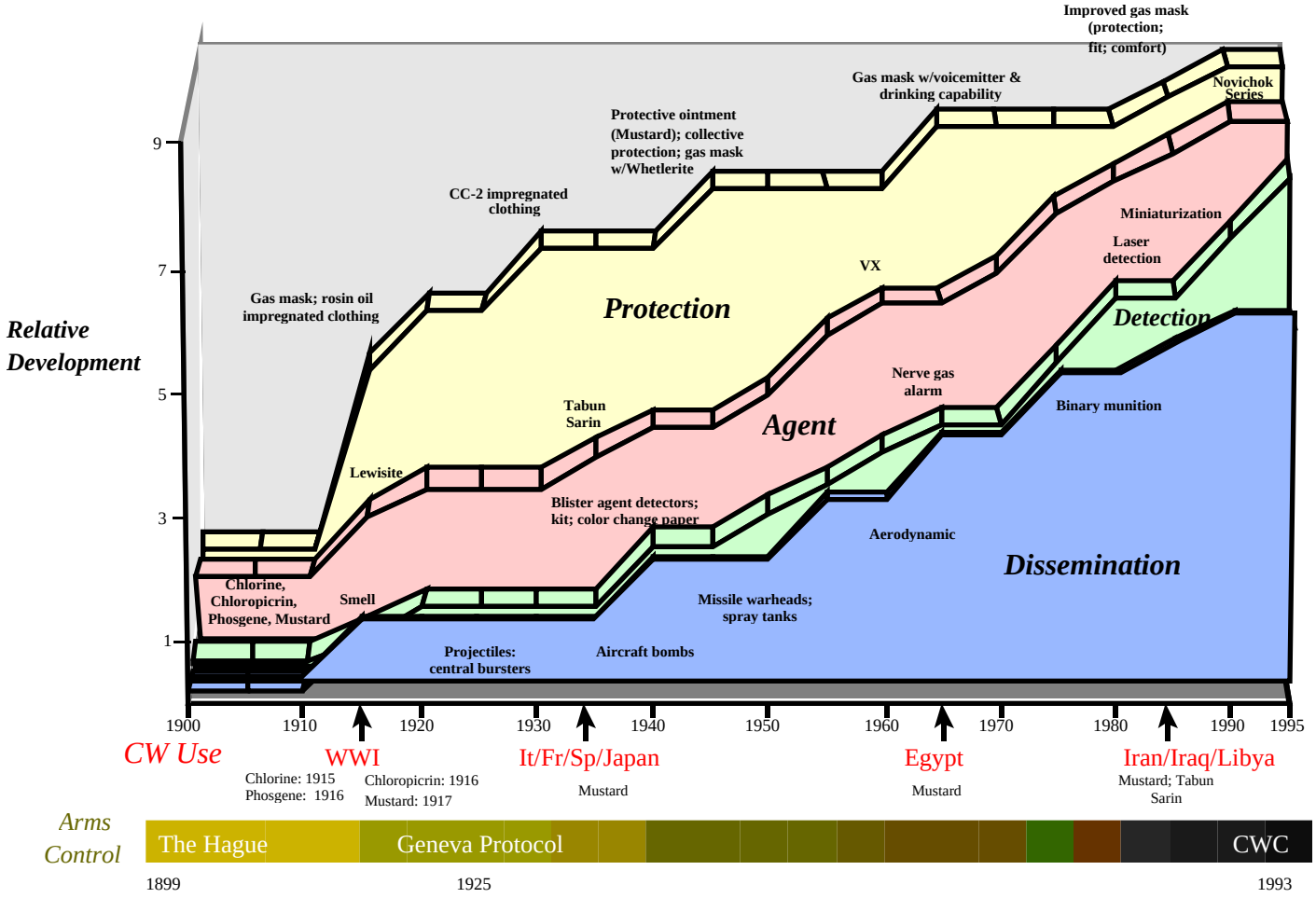

Figure 4.0-1. Relative Development of Chemical Weapons Technologies

Country*	Sec 4.1 Chemical Material Production	Sec 4.2 Dissemination, Dispersion and Weapons Testing	Sec 4.3 Detection, Warning and Identification	Sec 4.4 Chemical Defense Systems
Australia	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Bulgaria	♦♦♦	♦♦	♦♦	♦♦
Canada	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
China	♦♦♦♦	♦♦♦♦	♦♦	♦♦
Czech Republic	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Denmark	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Egypt	♦♦♦♦	♦♦♦	♦♦	♦♦
Finland	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
France	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Germany	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Hungary	♦♦♦♦	♦♦	♦♦♦	♦♦♦
India	♦♦♦♦	♦♦	♦♦	♦♦
Iran	♦♦♦♦	♦♦♦	♦♦	♦♦
Iraq	♦♦♦♦	♦♦♦♦	♦♦	♦♦
Israel	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Italy	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Japan	♦♦♦♦	♦♦♦	♦♦♦	♦♦♦
Libya	♦♦♦♦	♦♦♦	♦♦	♦♦
Netherlands	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
North Korea	♦♦♦♦	♦♦	♦♦	♦♦♦
Norway	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Pakistan	♦♦♦	♦♦	♦♦	♦♦
Poland	♦♦♦	♦♦	♦♦	♦♦
Russia	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Slovak Republic	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
South Africa	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦
South Korea	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Spain	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Sweden	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Switzerland	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Syria	♦♦♦	♦♦♦	♦♦	♦♦
United Kingdom	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
United States	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Viet Nam	♦♦♦	♦♦	♦♦	♦♦
Subnationals	♦♦♦	♦	♦♦	♦♦

Legend: Sufficient Technologies Capabilities: ♦♦♦♦ exceeds sufficient level ♦♦♦ sufficient level ♦♦ some ♦ limited

Because two or more countries have the same number of diamonds does not mean that their capabilities are the same. An absence of diamonds in countries of concern may indicate an absence of information, not of capability. The absence of a country from this list may indicate an absence of information, not capability.

Figure 4.0-2. Chemical Weapons Foreign Technology Assessment Summary

SECTION 4.1—CHEMICAL MATERIAL PRODUCTION

OVERVIEW

This subsection contains information on a number of the toxic chemicals and their most important precursors. Included are nerve agents (e.g., sarin, soman, tabun, VX), vesicants (e.g., sulfur mustards, lewisites, nitrogen mustards), and "classic" chemical agents (phosgene, cyanogen chloride, hydrogen cyanide). Important precursors are also listed. These include DF, DC, and QL, all used in producing nerve agents.

There are thousands of toxic chemicals that could be used in chemical weapons. Those listed have been stockpiled and/or used by a number of countries. The CWC Schedules of Chemicals (Figure 4.1-1) and the Australia Group (AG) list of precursors (Figure 4.1-2) are also provided to ensure recognition of those being considered either for verification provisions of the CWC or for export control. It should be remembered that the CWC schedules and the AG list do not include all of the known chemicals that have been or could be used to produce toxic agents.

Depending on the type of agent to be produced, there can be technical hurdles that must be overcome. "Classic" agents can be manufactured using existing chemical infrastructure, and most have legitimate commercial uses. Likewise, vesicants are not technologically complicated. The production of the nerve agents, however, requires significantly more sophisticated chemical processing. Some production processes require strict temperature control. Containment of toxic substances and gases can pose problems. Depending on the immediacy of use, purity of product can add a difficult dimension to production. In some cases, special equipment or handling is required to prevent corrosion of equipment and/or rapid deterioration of the product.

These hurdles can be overcome. If sufficient purity cannot be attained, an agent can be manufactured and used immediately. This presupposes the capability to manufacture a sufficient quantity in the time allotted. If special, corrosive-resistant equipment cannot be obtained, corroded equipment can be replaced when necessary or only a limited amount can be produced. If nerve agent production is technologically infeasible for a proliferant, a simpler agent (vesicant or classic agent) can be produced. Alternatives can entail increased costs, increased munition requirements, or reduced CW capability.

Some of the simpler **classic chemical agents** can be manufactured using existing chemical infrastructure. For example, phosgene is manufactured internally within chemical plants throughout the world for use as a chlorinating agent. Chlorination is the most common of chemical intermediate reactions in the chemical process industry. A reasonable size phosgene facility could be purchased with an investment of $10–$14 million. Similarly, hydrogen cyanide is currently manufactured worldwide as an intermediate in the manufacture of acrylic polymers and could be diverted for other uses or separately manufactured with about the same investment. In either instance the technologies are simple, well known, and require no specialized equipment. These CW agents require high munitions expenditures and are easily defeated by a gas mask, so that use would most likely be against unprotected populations and/or poorly equipped combatants.

Highlights

- There are many routes to produce most toxic chemicals.
- Thousands of chemicals exist that could be considered for chemical weapons.
- If corrosive-resistant equipment cannot be procured (for corrosive reactants and products), standard equipment can be used and replaced or discarded.
- Many CW precursors are common industrial chemicals. Some have been used in the past as agents in CW.
- Most technologies associated with CW production are old and available in the open literature.

Almost all proliferant states since World War I have manufactured **vesicants**, principally sulfur mustard, bis(2-chloroethyl) sulfide. There are several routes to this compound, none of which require sophisticated technology and/or special materials. The earlier producers favored the Levinstein Process, which consists of bubbling dry ethylene through sulfur monochloride, allowing the mixture to settle and (usually) distilling the remaining material. More recent production has involved chlorination of thiodiglycol, a relatively common material with a dual use as an ingredient in some inks. This method does not result in the solid byproducts of the Levinstein Process and can be more easily distilled. Drums of thiodiglycol, produced in the United States and illegally diverted from their intended recipients, were found by international inspectors after the Gulf War at Iraqi CW production sites. The principal problem experienced by initial manufacturers of sulfur mustard has been the insidious nature of this material. Virtually all those producing mustard have experienced a large number of industrial accidents resulting in casualties from mustard burns. Nitrogen mustards have been synthesized only in pilot plant quantities, but did not require any unusual processes or materials. Lewisite was produced by both the United States and the Soviet Union during World War II. The plants were quite small and unsophisticated by

today's standards. Lewisite is an arsenical and as such would require unusually large amounts of arsenates in its production.

Production of the **nerve agents** requires significantly more sophisticated chemical processing. In a majority of these materials, there are corrosive chemicals in the process that require specialized corrosion-resistant construction materials . With the exception of GA (tabun), manufactured by the Germans in World War II and the Iraqis during the Iran-Iraq war, G-agent production involves both chlorination and fluorination steps. Both of these steps require special and expensive construction materials. Reactors, degassers, distillation columns, and ancillary equipment made of high nickel alloys or precious metals are needed to contain the corrosive products and by products. Only the last step of the process involves the highly toxic material, so that special air handling equipment would be needed for only a small portion of the facility.

There are many process routes for producing the G- and V-agents; the majority involve the synthesis of methylphosphonic dichloride (DC) at some stage. The United States designed and built plants for four different processes for producing DC. Two were used in the stockpile production of GB (sarin), a third represented an upgrade of the stockpile production process to minimize waste, and the fourth represented a newer method used in producing material for binary weapons. The Soviet Union used a still different process to make DC and Iraq one similar to the last U.S. process. DC is a relatively easy material to store and to ship and need not be produced at the same site as the final product. It is very stable and has been stored for over 30 years with little deterioration. The size of the facility required to produce DC in militarily significant quantities ranges from very large down to room sized. A facility to produce DC with ancillary support would cost approximately $25 million not including pollution and environmental controls and waste treatment. Modern waste treatment and pollution abatement to U.S. standards would more than double the cost, although it is doubtful that a proliferant would build to these standards. The various DC production processes require some special corrosion-resistant equipment, generally glass-lined reactors and storage tanks, although not the ultra-expensive equipment required for later stages. DC has limited commercial use.

In the actual production of G-agents, the partially fluorinated DC (now a transient mixture called Di-Di) is reacted with an alcohol or alcohols and the product degassed and usually distilled. As noted previously, this is the toxic step of the reaction which requires air handling and filtering and also part of the highly corrosive portion that requires high nickel alloy (such as Hastelloy C) equipment and piping or precious metals (such as silver). The U.S. stockpile of GB was produced in this fashion and the former Soviet Union stockpiles of GB and GD (soman) by a variation of that process. The Iraqis used a somewhat over-fluorinated DC and mixed alcohols to produce a GB/GF mixture which was inherently unstable. Most of the alcohols involved in producing G-agents have large-scale commercial use. An exception is the alcohol for producing GD, pinacolyl alcohol, which has very limited pharmaceutical use.

Two principal general methods have been employed for V-agent production. The process used in the United States was called the Transester Process. It entails a rather difficult step in which phosphorus trichloride is methylated to produce methyl phosphonous dichloride. The material is reacted in turn with ethanol to form a diester and this material then transesterified to produce the immediate precursor of VX. The product is reacted with sulfur to form V-agent. This process has the advantage of being straightforward and producing high quality product. Conversely, it has the disadvantage of some difficult chemical engineering steps. The V-agent formed exclusively in the United States was VX. The former Soviet Union, the only other known producer of significant quantities of V-agent, did not produce VX per se, but rather a structurally different variant with the same molecular weight. The Soviets designed their process to make maximum use of production capability already available. The DC of the G-agent process was used in an Amiton process conducted in solution. The technique has the advantage of producing a single intermediate (DC). Disadvantages include the need to recover a highly toxic material from solution and to handle large quantities of contaminated solvent. In general, the V-agents are not easily distilled, and it is unlikely that a final purification process can be developed.

Incapacitating agent production is similar in many ways to the manufacture of pharmaceuticals, since these compounds are normally variations or derivatives of compounds used or postulated for use as pharmaceuticals. Since most pharmaceuticals are produced in relatively small quantities, production would entail a scale-up to an unusual process size for the type of reactions entailed. Moreover, virtually all candidate incapacitating agents are solids at room temperature and would require drying and grinding to an inhalable particulate. Given the tendency of many compounds to acquire a static charge and agglomerate, the grinding is a nontrivial manufacturing problem. The problems associated with manufacture (and use) of solid lethal agents (such as carbamates) are analogous to those experienced with incapacitants.

As a consequence of the diversity and complexity involved, it is difficult to provide any generic insights to **toxin** production. The only toxin to exist naturally in large quantities is ricin. It is a byproduct of castor oil production. Production of ricin is a physical separation. There are weak parallels with plutonium extraction or uranium isotope enrichment in nuclear processing. Toxin separation is much easier, less expensive, and requires smaller equipment. These advantages might make a toxin attractive to a poor, proliferating country. Most other toxins must be laboriously extracted in small quantities from the organism that secretes them. While synthetic toxins are possible, they are complex molecules, the synthesis of which in any significant amount would be difficult. Biotechnology may enhance the ability to produce toxins that were previously difficult to obtain in significant quantity.

Production of chemical agents in the past has anticipated their long-term storage since (in the instance of United States at least) they were viewed as deterrent weapons and by policy would not have been employed except in response to aggressor use.

This also meant that the agents and/or their weapons of employment might be stored for extensive periods of time. The life span of chemical weapons was first expected to be a decade. The requirement was later increased to 20 years when it became clear that munitions were likely to be stored at least that long. Chemical agents can either be stored in bulk quantities or loaded into munitions. With the nerve agents in particular, the quality of the initial material must be excellent and they must be stored under inert conditions with the absolute exclusion of oxygen and moisture. Generally an overlay of dry helium was employed to leak check munitions. A small amount of stabilizer (2–4 percent) was also used to extend agent life span. The United States stored agent in both bulk containers and in munitions. In the latter instance, the munitions were normally stored in revetted bunkers. This was particularly true when explosives and propellants were uploaded in the munitions. Storage of agents in explosive, uploaded munitions has both advantages and disadvantages. The principal advantage is speed of use when the munition is needed. There is no labor-intensive or time-consuming uploading process, and most munitions can be handled and shipped as if they were conventional munitions. The principal disadvantage is that explosives and propellants become part of the "system," and their storage and deterioration may complicate the handling of the chemical weapons. An illustrative case is seen in the 115-mm M55 rockets where burster, fuse, and rocket propellant cannot be easily and/or safely separated from the agent warhead before demilitarization. As a consequence, demilitarization is far more complicated and costly than it would be otherwise.

Agents stored in bulk in the United States are now stored entirely in large cylindrical "ton" containers similar to those used to store and ship many commercial chemicals. The procedure for the former Soviet Union's stockpile appears to have been to upload their stocks of nerve agent into munitions when produced, but to store them without the bursters or fuses. These munitions were then themselves stored in more conventional warehouse-like structures. Conversely, the older stocks of vesicants (i.e., mustard, lewisite and mustard-lewisite mixtures) are stored in bulk, apparently intended to be filled in munitions a short time before use. Bulk storage of the vesicants by the Russians is in large railroad-car-size tanks again located in warehouse-like structures. When the Iraqis produced chemical munitions they appeared to adhere to a "make and use" regimen. Judging by the information Iraq gave the United Nations, later verified by on-site inspections, Iraq had poor product quality for their nerve agents. This low quality was likely due to a lack of purification. They had to get the agent to the front promptly or have it degrade in the munition. This problem would have been less severe in their mustard rounds because of less aggressive impurities. The problem of degradation inhibited their ability to deploy and employ nerve weapons but probably did not have a great effect on their use of mustard. Using their weapons soon after production probably worked well in the Iran-Iraq War, where the skies over Iraq were controlled by the Iraqis. Unfortunately for the Iraqis, loss of air control in the Gulf meant the weapons could never reach the front. The chemical munitions found in Iraq after the Gulf War contained badly deteriorated agents and a significant proportion were visibly leaking.

Binary munitions were once intended by the United States as a means of retaining a retaliatory capability without the necessity of an agent stockpile. The relatively nontoxic intermediates could be stored separately and not placed in proximity to one another until just before use. This requires some human engineering to ensure the munitions designs permit simple, rapid mating of the ingredient containers and production of the lethal agent en route to the target. The binary system was envisioned almost exclusively for application to the standard nerve agents. Although at least three types of binary munitions were planned, only one (155-mm artillery shell) was in production when the United States ended CW production. The Russians claim to have considered binary munitions but not produced any. The Iraqis had a small number of bastardized binary munitions in which some unfortunate individual was to pour one ingredient into the other from a Jerry can prior to use.

Release of agent by enemy action during shipment is a disadvantage of unitary chemical munitions. The sinking of the U.S. cargo ship John Harvey in the harbor at Bari, Italy, during World War II and the subsequent unwitting release of a large quantity of mustard gas is a case in point. Mustard escaped from damaged munitions contaminating those escaping the sinking ship and civilians on shore.

RATIONALE (See Table 4.1-1)

Since there are so many toxic chemicals that could be used in chemical weapons, only those agents of major significance and their precursors have been included. These toxic chemicals have been designated of most concern by the world community. The majority of nerve agents, sulfur mustards, lewisites, and some of the nitrogen mustards are listed in the CWC schedules of chemicals (Figure 4.1-1). Each nerve agent is representative of a family (hundreds to thousands) of chemicals. Those specifically included have been produced and stockpiled by a number of countries. The precursor DC is the fundamental building block for a significant portion of G- and V-agents. The classic chemicals (phosgene, cyanogen chloride, and hydrogen cyanide) have been included since they are so readily available that a proliferant could obtain them easily. Although these chemical agents would require high munitions expenditures and are easily defeated by a gas mask, they could be used effectively against unprotected populations and/or poorly equipped combatants.

Toxins have not been included in this subsection but can be found in Section 3, Biological Weapons Technologies. Although toxins are not living organisms, they are made by living organisms. They are listed in Schedule 1A of the CWC and the biological agent part of the Australia Group list.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 4.0-2)

Any country with a chemical industry has the capability, if not the intent, to produce toxic chemicals. Most of the technologies are old and described in the open literature. The countries listed in Figure 4.0-2 have the capability or have used chemical weapons in the past and therefore are technically capable of producing chemical weapons. The assessment is not an indication of current intent. Many of these countries have signed/ratified the CWC.

There have been numerous press reports of toxic chemicals produced in Russia that are not covered in the CWC schedules. Vil Mirzayanov, a chemist and former high-ranking scientist in the former Soviet Union's chemical weapons program, published an article in *Kuranty* in 1991 (and co-authored another article in 1992 in the *Moscow News*) in which he claimed that Russia had developed new kinds of chemical weapons. Substances like Novichok (A-230, A-232, and A-234) are chemical agents that the Russians are said to have developed in spite of agreement to halt production of chemical weapons. These statements were repeated by a former head of the Russian demilitarization program.

There has been press coverage of a large, underground facility being built at Tarhunah in Libya that the United States claims is designed as a chemical production facility. Libya dropped chemical agents obtained from Iran from a transport aircraft against Chadian troops in 1987. Late in 1988, Libya completed a chemical agent facility at Rabta as part of its drive to develop an indigenous CW capability. When the United States brought international attention to the plant, Libya responded by fabricating a fire to make it appear that the facility had been seriously damaged. This plant was closed in 1990, but the Libyans announced its reopening in September 1995 as a pharmaceutical facility. The Rabta facility is still capable of producing chemical agents.

Since the late 1980's, North Korea has expanded its chemical warfare program. Today it can produce large quantities of blister, blood, choking, and possibly nerve agents. It also maintains a number of facilities involved in producing or storing precursors for toxic chemicals, the agents themselves, and weapons. As mentioned previously, Iran delivered limited quantities of blister and blood agents against Iraqi soldiers late in the Iran-Iraq War. Iran has increased its rate of production since 1984 and has produced at least several hundred tons of blister, blood, and choking agents. Some of these agents have been weaponized to support ground combat operations.

Before the Gulf War, Iraq had become nearly self-sufficient in producing many precursors and had developed a variety of chemical weapons on its own. The chief inspector of the UN Special Commission chemical destruction group said that all known chemical munitions, agents, and precursors in Iraq had been eliminated by May 1994. Many think that Iraq can revive its CW capability in a matter of months in the absence of UN monitoring or import controls.

On the Asian subcontinent, India and Pakistan are capable of developing chemical weapons. India has a large chemical industry that produces numerous dual-use chemicals that are potential precursors. In June 1997, India submitted CW declarations to the CWC governing body in The Hague. This was the first time the Indians publicly acknowledged a CW program. Pakistan has procured dual-use precursors from foreign sources and is moving slowly toward the capability of producing precursors.

The Aum Shinrikyo cult in Japan proved that subnational groups can obtain the expertise and ingredients to threaten society with chemical agents. A Senate Permanent Subcommittee on Investigations study indicated that the cult had produced the nerve agents sarin, soman, tabun, and VX, as well as phosgene and sodium cyanide. Toxic chemicals were used at least twice, including the Tokyo subway attack that left 12 dead and more than 5,000 injured.

The following Schedules list toxic chemicals and their precursors. For the purposes of implementing this Convention, these Schedules identify chemicals for the application of verification measures according to the provisions of the Verification Annex. Pursuant to Article II, subparagraph 1(a), these Schedules do not constitute a definition of chemical weapons.

(Whenever reference is made to groups of dialkylated chemicals, followed by a list of alkyl groups in parentheses, all chemicals possible by all possible combinations of alkyl groups listed in the parentheses are considered as listed in the respective Schedule as long as they are not explicitly exempted. A chemical marked "*" on Schedule 2, part A, is subject to special thresholds for declaration and verification, as specified in Part VII of the Verification Annex.)

Schedule 1 (CAS registry number)

A. Toxic chemicals:

(1) O-Alkyl ($\leq C_{10}$, incl. cycloalkyl) alkyl (Me, Et, n-Pr or i-Pr)-phosphonofluoridates,
e.g., sarin: O-Isopropyl methylphosphonofluoridate (107-44-8)
soman: O-Pinacolyl methylphosphonofluoridate (96-64-0)

(2) O-Alkyl ($\leq C_{10}$, incl. cycloalkyl) N,N-dialkyl (Me, Et, n-Pr or i-Pr) phosphoramidocyanidates,
e.g., tabun: O-Ethyl N,N-dimethyl phosphoramidocyanidate (77-81-6)

(3) O-Alkyl (H or $\leq C_{10}$, incl. cycloalkyl) S-2-dialkyl (Me, Et, n-Pr or i-Pr)-aminoethyl alkyl (Me, Et, n-Pr or i-Pr) phosphonothiolates and corresponding alkylated or protonated salts,
e.g., VX: O-Ethyl S-2-diisopropylaminoethyl methyl phosphonothiolate (50782-69-9)

(4) Sulfur mustards:
2-Chloroethylchloromethylsulfide (2625-76-5)
Mustard gas: Bis(2-chloroethyl)sulfide (505-60-2)
Bis(2-chloroethylthio)methane (63869-13-6)
Sesquimustard: 1,2-Bis(2-chloroethylthio)ethane (3563-36-8)
1,3-Bis(2-chloroethylthio)-n-propane (63905-10-2)
1,4-Bis(2-chloroethylthio)-n-butane (142868-93-7)
1,5-Bis(2-chloroethylthio)-n-pentane (142868-94-8)
Bis(2-chloroethylthiomethyl)ether (63918-90-1)
O-Mustard: bis(2-chloroethylthioethyl)ether (63918-89-8)

(5) Lewisites:
Lewisite 1: 2-Chlorovinyldichloroarsine (541-25-3)
Lewisite 2: Bis(2-chlorovinyl)chloroarsine (40334-69-8)
Lewisite 3: Tris(2-chlorovinyl)arsine (40334-70-1)

(6) Nitrogen mustards:
HN1: Bis(2-chloroethyl)ethylamine (538-07-8)
HN2: Bis(2-chloroethyl)methylamine (51-75-2)
HN3: Tris(2-chloroethyl)amine (555-77-1)

(7) Saxitoxin (35523-89-8)

(8) Ricin (9009-86-3)

B. Precursors:

(9) Alkyl (Me, Et, n-Pr or i-Pr) phosphonyldifluorides
e.g. DF: Methylphosphonyldifluoride (676-99-3)

(10) O-Alkyl (H or $\leq C_{10}$, incl. cycloalkyl) O-2-dialkyl (Me, Et, n-Pr or i-Pr)-aminoethyl alkyl (Me, Et, n-Pr or i-Pr) phosphonites and corresponding alkylated or protonated salts e.g. QL: O-Ethyl O-2-diisopropylaminoethyl methylphosphonite (57856-11-8)

(11) Chlorosarin: O-Isopropyl methylphosphonochloridate (1445-76-7)

(12) Chlorosoman: O-Pinacolyl methylphosphonochloridate (7040-57-5)

(cont'd)

Figure 4.1-1. Chemical Weapons Convention Schedules of Chemicals

Schedule 2

A. Toxic chemicals:

(1) Amiton: O,O-Diethyl S-[2-(diethylamino)ethyl] phosphorothiolate (78-53-5)
and corresponding alkylated and protonated salts

(2) PFIB: 1,1,3,3,3-Pentafluoro-2-(trifluoromethyl)-1-propene (382-21-8)

(3) BZ: 3-Quinuclidinyl benzilate (*) (6581-06-2)

B. Precursors:

(4) Chemicals, except for those listed in Schedule 1, containing a phosphorus atom to which is bonded one methyl, ethyl, or propyl (normal or iso) group but not further carbon atoms, e.g.,
Methylphosphonyl dichloride (676-97-1)
Dimethyl methylphosphonate (756-79-6)
Exemption: Fonofos: O-Ethyl S-phenyl ethylphosphonothiolothionate (944-22-9)

(5) N,N-Dialkyl (Me, Et, n-Pr or i-Pr) phosphoramidic dihalides

(6) Dialkyl (Me, Et, n-Pr or i-Pr) N,N-dialkyl (Me, Et, n-Pr or i-Pr)-phosphoramidates

(7) Arsenic trichloride (7784-34-1)

(8) 2,2-Diphenyl-2-hydroxyacetic acid (76-93-7)

(9) Quinuclidine-3-ol (1619-34-7)

(10) N,N-Dialkyl (Me, Et, n-Pr or i-Pr) aminoethyl-2-chlorides and corresponding protonated salts

(11) N,N-Dialkyl (Me, Et, n-Pr or i-Pr) aminoethane-2-ols and corresponding protonated salts
Exemptions: N,N-Dimethylaminoethanol (108-01-0) and corresponding protonated salts
N,N-Diethylaminoethanol (100-37-8) and corresponding protonated salts

(12) N,N-Dialkyl (Me, Et, n-Pr or i-Pr) aminoethane-2-thiols and corresponding protonated salts

(13) Thiodiglycol: Bis(2-hydroxyethyl)sulfide (111-48-8)

(14) Pinacolyl alcohol: 3,3-Dimethylbutane-2-ol (464-07-3)

Schedule 3

A. Toxic chemicals:

(1) Phosgene: carbonyl dichloride (75-44-5)

(2) Cyanogen chloride (506-77-4)

(3) Hydrogen cyanide (74-90-8)

(4) Chloropicrin: Trichloronitromethane (76-06-2)

B. Precursors:

(5) Phosphorus oxychloride (10025-87-3)

(6) Phosphorus trichloride (7719-12-2)

(7) Phosphorus pentachloride (10026-13-8)

(8) Trimethyl phosphite (121-45-9)

(9) Triethyl phosphite (122-52-1)

(10) Dimethyl phosphite (868-85-9)

(11) Diethyl phosphite (762-04-9)

(12) Sulfur monochloride(10025-67-9)

(13) Sulfur dichloride (10545-99-0)

(14) Thionyl chloride (7719-09-7)

(15) Ethyldiethanolamine (139-87-7)

(16) Methyldiethanolamine (105-59-9)

(17) Triethanolamine (102-71-6)

Source: *The Chemical Weapons Convention,* "Annex on Chemicals," Part B.

Figure 4.1-1. Chemical Weapons Convention Schedules of Chemicals (cont'd)

Chemical	C.A.S. #
1. Thiodiglycol	111-48-8
2. Phosphorus Oxychloride	10025-87-3
3. Dimethyl Methylphosphonate	756-79-6
4. Methyl Phosphonyl Difluoride	676-99-3
5. Methyl Phosphonyl Dichloride	676-97-1
6. Dimethyl Phosphite	868-85-9
7. Phosphorus Trichloride	7719-12-2
8. Trimethyl Phosphite	121-45-9
9. Thionyl Chloride	7719-09-7
10. 3-Hydroxy-1-methylpiperidine	3554-74-3
11. N,N-Diisopropyl-ß-Aminoethyl Chloride	96-79-7
12. N,N-Diisopropyl-ß-Aminoethane Thiol	5842-07-9
13. 3-Quinuclidinol	1619-34-7
14. Potassium Fluoride	7789-23-3
15. 2-Chloroethanol	107-07-3
16. Dimethylamine	124-40-3
17. Diethyl Ethylphosphonate	78-38-6
18. Diethyl N,N-Dimethylphosphoramidate	2404-03-7
19. Diethyl Phosphite	762-04-9
20. Dimethylamine Hydrochloride	506-59-2
21. Ethyl Phosphinyl Dichloride	1498-40-4
22. Ethyl Phosphonyl Dichloride	1066-50-8
23. Ethyl Phosphonyl Difluoride	753-98-0
24. Hydrogen Fluoride	7664-39-3
25. Methyl Benzilate	76-89-1
26. Methyl Phosphinyl Dichloride	676-83-5
27. N,N-Diisopropyl-ß-Amino-Ethanol	96-80-0
28. Pinacolyl Alcohol	464-07-3
29. O-Ethyl 2-Diisopropylaminoethyl Methylphosphonite	57856-11-8

Chemical	C.A.S. #
30. Triethyl Phosphite	122-52-1
31. Arsenic Trichloride	7784-34-1
32. Benzilic Acid	76-93-7
33. Diethyl Methylphosphonite	15715-41-0
34. Dimethyl Ethylphosphonate	6163-75-3
35. Ethyl Phosphinyl Difluoride	430-78-4
36. Methyl Phosphinyl Difluoride	753-59-3
37. 3-Quinuclidone	3731-38-2
38. Phosphorus Pentachloride	10026-13-8
39. Pinacolone	75-97-8
40. Potassium Cyanide	151-50-8
41. Potassium Bifluoride	7789-29-9
42. Ammonium Bifluoride	1341-49-7
43. Sodium Bifluoride	1333-83-1
44. Sodium Fluoride	7681-49-4
45. Sodium Cyanide	143-33-9
46. Tri-ethanolamine	102-71-6
47. Phosphorus Pentasulphide	1314-80-3
48. Di-isopropylamine	108-18-9
49. Diethylaminoethanol	100-37-8
50. Sodium Sulphide	1313-82-2
51. Sulphur Monochloride	10025-67-9
52. Sulphur Dichloride	10545-99-0
53. Triethanolamine Hydrochloride	637-39-8
54. N,N-Diisopropyl-2-Aminoethyl Chloride Hydrochloride	4261-68-1

Source: ACDA Fact Sheet on Australia Group Export Controls, November 7, 1995 (current as of September 6, 1997).

Figure 4.1-2. Australia Group Chemicals

Table 4.1-1. Chemical Material Production Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Manufacturing processes for O-Alkyl (≤C_{10}, incl. cycloalkyl) alkyl (Me, Et, n-Pr or i-Pr)-phosphono-fluoridates, e.g., **sarin (GB)**: O-Isopropyl methylphosphonofluori-date (CAS: 107-44-8)	Sovereign States: capable of annual production of approx. 100 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	Phosphorus trichloride; DF; DC; hydrogen fluoride; isopropanol	Needs expensive corrosive-resistant equipment such as hastelloy or silver	None identified
Manufacturing processes for O-Alkyl (≤C10, incl. cycloalkyl) alkyl (Me, Et, n-Pr or i-Pr)-phosphono-fluoridates, e.g., **soman (GD)**: O-Pinacolyl methylphosphono-fluoridate (CAS: 96-64-0)	Sovereign States: capable of annual production of approx. 100 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	Phosphorus trichloride; DC; hydrogen fluoride; pinacolyl alcohol	Needs expensive corrosive-resistant equipment such as hastelloy or silver	None identified
Manufacturing processes for O-Alkyl (≤C_{10}, incl. cycloalkyl) N,N-dialkyl (Me, Et, n-Pr or i-Pr) phosphoramidocyani-dates, e.g., **tabun (GA)**: O-Ethyl N,N-dimethyl-phosphoramidocyanidate (CAS: 77-81-6)	Sovereign States: capable of annual production of approx. 200 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	Phosphorus oxychloride or phosphorus trichloride; sodium cyanide; dimethlyamine; ethyl alcohol	None identified	None identified
Manufacturing processes for O-Alkyl (H or ≤C_{10}, incl. cycloalkyl) Me, Et, n-Pr or i-Pr)-aminoethyl alkyl (Me, Et, n-Pr or i-Pr) phosphonothiolates and corresponding alkylated or protonated salts, e.g., **VX** (CAS: 50782-69-9)	Sovereign States: capable of annual production of approx. 200 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	QL; sulfur or DC if Amiton-like process is used	Inert atmosphere High-temperature methylation equipment (QL process)	None identified
Manufacturing processes for Phosphonochloridates, e.g., **chlorosarin**: O-Isopropyl methyl-phosphonochloridate (CAS: 1445-76-7)	Sovereign States: capable of annual production of approx. 300 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	DC	Glass-lined reactors	None identified

(cont'd)

Table 4.1-1. Chemical Material Production Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Manufacturing processes for Sulfur mustards: (see Figure 4.1-1 for names) - CAS: 2625-76-5 - CAS: 505-60-2 - CAS: 63869-13-6 - CAS: 3563-36-8 - CAS: 63905-10-2 - CAS: 142868-93-7 - CAS: 142868-94-8 - CAS: 63918-90-1 - CAS: 63918-89-8	Sovereign States: capable of annual production of approx. 500 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	Sulfur monochloride or sulfur dichloride or Thiodiglycol	None identified	None identified
Manufacturing processes for lewisites: - Lewisite 1: 2-Chloro-vinyldichloroarsine (CAS: 541-25-3) - Lewisite 2: Bis(2-chlorovinyl)chloro-arsine (CAS: 40334-69-8) - Lewisite 3: Tris(2-chlorovinyl)arsine (CAS: 40334-70-1)	Sovereign States: capable of annual production of approx. 500 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	Arsenic trichloride	None identified	None identified
Manufacturing processes for Nitrogen mustards: - HN1: Bis(2-chloro-ethyl)ethylamine (CAS: 538-07-8) - HN2: Bis(2-chloro-ethyl)methylamine (CAS: 51-75-2) - HN3: Tris(2-chloro-ethyl)amine (CAS: 555-77-1)	Sovereign States: capable of annual production of approx. 500 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	HN 1: ethyl diethanolamine HN 2: methyl diethanolamine HN 3: triethanolamine	Glass- or enamel-lined equipment	None identified

(cont'd)

Table 4.1-1. Chemical Material Production Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Manufacturing processes for Amiton: O,O-Diethyl S-[2-(diethylamino)ethyl] phosphorothiolate and corresponding alkylated or protonated salts (CAS: 78-53-5)	Sovereign States: capable of annual production of approx. 500 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	None	Normally made in solution, extraction equipment	None identified
Manufacturing processes for PFIB: 1,1,3,3,3-Pentafluoro-2-(trifluoromethyl)-1-propene (CAS: 382-21-8)	Sovereign States: capable of annual production of approx. 2,000 tons Subnational: capable of producing any amount	CWC; WA ML 7; USML XIV	None	Needs expensive corrosion resistant equipment such as Hastelloy or silver	None identified
Manufacturing processes for Phosgene: carbonyl dichloride (CAS: 75-44-5)	Sovereign States: capable of annual production of approx. 2,000 tons Subnational: capable of producing any amount	CWC (exempted from WA ML); USML XIV	None	Corrosion resistant equipment	None identified
Manufacturing processes for Cyanogen chloride (CAS: 506-77-4)	Sovereign States: capable of annual production of approx. 2,000 tons Subnational: capable of producing any amount	CWC (exempted from WA ML); USML XIV	None	None identified	None identified
Manufacturing processes for Hydrogen cyanide (CAS: 74-90-8)	Sovereign States: capable of annual production of approx. 5,000 tons Subnational: capable of producing any amount	CWC (exempted from WA ML); USML XIV	None	None identified	None identified
Manufacturing processes for Alkyl (Me, Et, n-Pr or i-Pr) phosphonyldifluorides, e.g., **DF:** Methyl-phosphonyldifluoride (CAS: 676-99-3)	Sovereign States: capable of annual production of approx. 200 tons Subnational: capable of producing any amount	CWC; AG List; WA ML-7; CCL Cat 1E	DC; hydrogen fluoride	Production equipment made of Hastelloy or other high nickel alloys; silver	None identified

(cont'd)

Table 4.1-1. Chemical Material Production Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Manufacturing processes for Alkyl (Me, Et, n-Pr or i-Pr) phosphonylchlorides, e.g., **DC**: Methyl-phosphonyl dichloride (CAS: 676-97-1) Note: This material, rather than DF, is the fundamental building block of a significant portion of G and V agents.	Sovereign States: capable of annual production of approx. 400 tons Subnational: capable of producing any amount	CWC; AG List; WA ML-7; CCL Cat IE	Thionyl chloride or phosgene or phosphorous pentachloride. Dimethylmethylphos-phonate (DMMP) (many production processes available).	Glass-lined vessels Glass-lined distillation columns	None identified
Manufacturing processes for O-Alkyl (H or $\leq C_{10}$, incl. cycloalkyl) O-2-dialkyl (Me, Et, n-Pr or i-Pr)-aminoethyl alkyl (Me, Et, n-Pr or i-Pr) phosphonites and corresponding alkylated or protonated salts, e.g., **QL** (CAS: 57856-11-8)	Sovereign States: capable of annual production of approx. 200 tons Subnational: capable of producing any amount	CWC; AG List; WA ML 7; CCL Cat 1E	TR (diethyl methylphosphonite) KB (2-(N-N-diethylamino) ethanol). Similar esters and amino alcohols.	Waste treatment incinerators Distillation columns High-temperature methylation equipment	None identified

Table 4.1-2. Chemical Material Production Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
Manufacturing processes for O-Alkyl (≤C_{10}, incl. cycloalkyl) alkyl (Me, Et, n-Pr or i-Pr)-phosphono–fluoridates, e.g., **sarin (GB)**: O-Isopropyl methylphosphonofluoridate (CAS: 107-44-8)	Oxidation; alkylation; fluorination; esterification. Large power needs. Must be distilled and stabilized unless manufactured for immediate use.	Troop concentrations, sabotage.	A number of production processes have been documented
Manufacturing processes for O-Alkyl (≤C_{10}, incl. cycloalkyl) alkyl (Me, Et, n-Pr or i-Pr)-phosphonofluoridates, e.g., **soman (GD)**: –O-Pinacolyl methylphosphonofluoridate (CAS: 96-64-0)	Oxidation; alkylation; fluorination; esterification. Large power needs. Must be distilled and stabilized unless manufactured for immediate use.	Troop concentrations, sabotage.	A number of production processes have been documented
Manufacturing processes for O-Alkyl (≤C_{10}, incl. cycloalkyl) N,N-dialkyl (Me, Et, n-Pr or i-Pr) phosphoramidocyanidates, e.g., **tabun (GA)**: O-Ethyl N,N-dimethyl phosphoramido-cyanidate (CAS: 77-81-6)	Cyanation reaction	Troop concentrations, sabotage.	A number of production processes have been documented
Manufacturing processes for O-Alkyl (H or ≤C_{10}, incl. cycloalkyl) Me, Et, n-Pr or i-Pr)-aminoethyl alkyl (Me, Et, n-Pr or i-Pr) phosphonothiolates and corresponding alkylated or protonated salts, e.g., **VX** (CAS: 50782-69-9)	Alkylation reaction or use of Amiton-like process. Product should be stabilized.	Troop concentrations, sabotage, terrain denial	A number of production processes have been documented
Manufacturing processes for Phosphonochloridates, e.g., **chlorosarin**: O-Isopropyl methylphosphonochloridate (CAS: 1445-76-7)	No fluorinated reactor involved; therefore, do not need Hastelloy although glass-lined vessel required. Easier to produce, but far less toxic.	Sabotage (more applicable to subnational)	A number of production processes have been documented

(cont'd)

Table 4.1-2. Chemical Material Production Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Manufacturing processes for **Sulfur mustards**: (see Figure 4.1-1 for names) - CAS: 2625-76-5 - CAS: 505-60-2 - CAS: 63869-13-6 - CAS: 3563-36-8 - CAS: 63905-10-2 - CAS: 142868-93-7 - CAS: 142868-94-8 - CAS: 63918-90-1 - CAS: 63918-89-8	Ventilation; filtration	Troop concentrations, sabotage, terrain denial	A number of production processes have been documented
Manufacturing processes for **lewisites**: - Lewisite 1: 2-Chlorovinyl-dichloroarsine (CAS: 541-25-3) - Lewisite 2: Bis(2-chlorovinyl)-chloroarsine (CAS: 40334-69-8) - Lewisite 3: Tris(2-chlorovinyl)-arsine (CAS: 40334-70-1)	Corrosion; potential for explosive reactions	Troop concentrations, sabotage	A number of production processes have been documented
Manufacturing processes for **Nitrogen mustards**: - HN1: Bis(2-chloroethyl)-ethylamine (CAS: 538-07-8) - HN2: Bis(2-chloroethyl)-methylamine (CAS: 51-75-2) - HN3: Tris(2-chloroethyl)amine (CAS: 555-77-1)	Chlorination; neutralization	Troop concentrations, sabotage	A number of production processes have been documented including those to make other nitrogen mustards not listed on CWC schedules
Manufacturing processes for **PFIB**: 1,1,3,3,3-Pentafluoro-2-(trifluoromethyl)-1-propene (CAS: 382-21-8)	Byproduct of Teflon manufacture	Gas-mask penetrant	A number of production processes have been documented
Manufacturing processes for **Phosgene**: carbonyl dichloride (CAS: 75-44-5)	Used heavily in commercial processes	Nonpersistent gas	A number of production processes have been documented

(cont'd)

Table 4.1-2. Chemical Material Production Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Manufacturing processes for **Cyanogen chloride** (CAS: 506-77-4)	None identified	Quick-acting casualty agent Degradation of mask filters	A number of production processes have been documented
Manufacturing processes for **Hydrogen cyanide** (CAS: 74-90-8)	Used heavily in acrylic industries	Bombs, grenades	A number of production processes have been documented
Manufacturing processes for Alkyl (Me, Et, n-Pr or i-Pr) phosphonyldifluorides, e.g., **DF**: Methylphosphonyldifluoride (CAS: 676-99-3) .	Fluorination reaction; corrosion	Key component in binary G agents	A number of production processes have been documented
Manufacturing processes for Alkyl (Me, Et, n-Pr or i-Pr) phosphonylchlorides, e.g., **DC**: Methylphosphonyl dichloride (CAS: 676-97-1) Note: This material rather than DF is the fundamental building block of a significant portion of G and V agents.	Chlorination reaction	Used to make DF and Di-Di mix Also can be used in some V agent processes	A number of production processes have been documented
Manufacturing processes for O-Alkyl (H or $\leq C_{10}$, incl. cycloalkyl) O-2-dialkyl (Me, Et, n-Pr or i-Pr)-aminoethyl alkyl (Me, Et, n-Pr or i-Pr) phosphonites and corresponding alkylated or protonated salts, e.g., **QL** (CAS: 57856-11-8)	Transesterification reaction High-temperature methylation	Component of VX binary weapon; may be intermediate in VX process	A number of production processes have been documented

SECTION 4.2—DISSEMINATION, DISPERSION, AND WEAPONS TESTING

OVERVIEW

Perhaps the most important factor in the effectiveness of chemical weapons is the efficiency of dissemination. This section lists a variety of technologies that can be used to weaponize toxic chemical agents. Munitions include bombs, submunitions, projectiles, warheads, and spray tanks. Techniques of filling and storage of munitions are important. The principal method of disseminating chemical agents has been the use of explosives. (Figure 4.2-1 shows an example of a U.S. chemical bomb, the MC-1.) These usually have taken the form of central bursters expelling the agent laterally. Efficiency is not particularly high in that a good deal of the agent is lost by incineration in the initial blast and by being forced onto the ground. Particle size will vary, since explosive dissemination produces a bimodal distribution of liquid droplets of an uncontrollable size but usually having fine and coarse modes. For flammable aerosols, sometimes the cloud is totally or partially ignited (flashing) in the dissemination process. For example, explosively disseminated VX ignited roughly one third of the time it was employed. The phenomenon was never fully understood or controlled despite extensive study. A solution would represent a major technological advance.

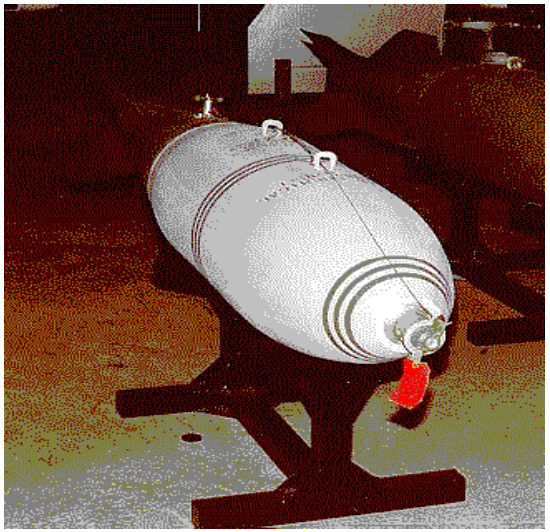

Figure 4.2-1. MC-1 Gas Bomb

Highlights

- Efficiency of dissemination is the most important factor in the effectiveness of chemical weapons.
- Much of the agent is lost in an explosive dissemination by incineration and by being forced onto the ground.
- Flammable aerosols frequently “flash” (ignite) when explosively disseminated.
- The environment (winds and temperature) are important factors in CW dissemination.

Aerodynamic dissemination technology allows nonexplosive delivery from a line source. Although this method provides a theoretical capability of controlling the size of the particle, the altitude of dissemination must be controlled and the wind direction and velocity known. Accurate weather observations can enable the attacker to predict wind direction and velocity in the target area.

An important factor in the effectiveness of chemical weapons is the efficiency of dissemination as it is tailored to the types of agent. The majority of the most potent of chemical agents are not very volatile. Indeed, the most volatile of the G-agents is GB (sarin), which has a volatility near that of water. All are nonvolatile liquids or solids at room temperature. VX is an oily liquid.

An advanced proliferant might attempt to develop on-board sensor systems for initiation and control of agent dissemination/dispersal for ballistic missiles, cruise missiles, and artillery. In these cases, the sensor (target-detection device) may employ technologies common to other electronic fuzing applications. The efficacy of explosives and pyrotechnics for dissemination is limited by the flammable nature of some agents.

In some respects, long-range strategic weapons pose a lesser problem than short-range tactical weapons that are fired over, or in the vicinity of, one’s own forces. The agent must be dispersed within the boundary layer (<200–300 ft above the ground) and yet high enough to allow effective dispersal of the agent. This poses design problems because the ground/target detection device must be substantially more sensitive than for conventional munitions. The increased sensitivity also results in increased susceptibility to false firing due to noise, mutual interference, and electronic countermeasures (ECM).

Casualties due to premature initiation of the warhead are unacceptable in tactical weapons. Accordingly, an additional function such as a simple electrical or mechanical timer may be used to arm the height-of-burst sensor.

A more recent attempt to control aerosol particle size on target has been the use of **aerodynamic dissemination** and sprays as line sources. By modification of the rheological properties of the liquid, its breakup when subjected to aerodynamic stress can theoretically be controlled and an idealized particle distribution achieved. In practice, the task is more difficult, but it represents an area where a technological advance could result in major munition performance improvements. The altitude of dissemination must be controllable and the wind direction and velocity known for a disseminated liquid of a predetermined particle size to predictably reach the ground and reliably hit a target.

Thermal dissemination, wherein pyrotechnics are used to aerosolize the agent has been used particularly to generate fine, inhalable clouds of incapacitants. Most of the more complex agent molecules, however, are sensitive to high temperatures and can deteriorate if exposure is too lengthy. Solids are a notoriously difficult problem for dissemination, since they tend to agglomerate even when pre-ground to desired sizes.

Dispersion considers the relative placement of the chemical agent munition upon or adjacent to a target immediately before dissemination so that the material is most efficiently used. For example, the artillery rockets of the 1950's and early 1960's employed a multitude of submunitions so that a large number of small agent clouds would form directly on the target with minimal dependence on meteorology. Another variation of this is multiple "free" aerial sprays such as those achieved by the BLU 80/B Bigeye weapon and the multiple launch rocket system. While somewhat wind dependent, this technique is considerably more efficient in terms of agent quantities.

Testing requirements for munitions seek to measure the efficacy of dissemination. This has been done historically on instrumented grids with samples of the disseminated material taken at known positions. The positions are assigned area values and these are integrated to determine total dosage and dose isopleths. While the technique was constantly improved, it still was crude by most standards and required numerous tests to provide useful information. Instrumental methods such as versions of light detection and ranging (LIDAR) may well be better suited to more accurate measures but without the signature of the chemical grids.

Modeling dissemination patterns for agent laydown can be an effective way to predict dispersal without physical testing. Little testing would be required given good, verified models. The problem, however, is model verification.

RATIONALE (See Table 4.2-1)

Many dissemination technologies have been included because many are available to a proliferant. In World War I, canisters of chlorine were simply opened to allow the gas to drift across enemy lines. Although this produced limited results, it is indicative of the simplicity of potential means of dispersion. Although central bursters have limitations, countries usually use this method in the early stages of CW development, although it does not have to be the first one. There is sufficient open literature describing the pros and cons of various types of dissemination to dictate the consideration of all of them by a proliferant. Most countries could develop the toxic agents and adapt their standard munitions to carry the agents. It is much more difficult, however, to achieve success in effective dispersion and dissemination. Weather observation and forecasting are essential to increase the probability of effective CW dissemination and reduce the risk of injuring friendly forces.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 4.0-2)

As stated previously, most countries have the capability to develop chemical weapons. Those with a well-developed military infrastructure could readily adapt existing munitions for chemical warfare. During the Iran-Iraq War, Iraq delivered mustard and tabun with artillery shells, aerial bombs, missiles, and rockets. Virtually any country or subnational group with significant resources has sufficient capability to attain the minimum capability that would be needed to meet terrorist aims. Any nation with substantial foreign military sales or indigenous capability in conventional weapons will have (or have ready access to) both the design know-how and components required to implement at least a moderate capability.

Table 4.2-1. Dissemination, Dispersion, and Weapons Testing Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Projectile cases for CW agents	Ability to produce fillable, fireable, and leakproof munition casings	USML II, IV; WA ML 2, 4	High fragmentation steels and corrosion/leak resistant casings	Projectile forging, casing production, high-integrity weld or ball seals, inert gas insertion, helium leak check equipment, acoustic metal flaw detection.	Liquid fill ballistic programs Dissemination prediction models
Warheads for CW missile systems	Ability to produce casings for either bulk liquid or sub-munitions capable of appropriate opening for dissemination	USML IV; WA ML 4; MTCR 4	Corrosion/leak-resistant casings	High-integrity weld or ball seals, inert gas insertion, helium leak check equipment. Ability to dynamically balance loaded warhead.	Ballistic programs able to account for effects of liquid fills Dissemination and dispersion prediction capabilities
Electronic time fuzes	Accuracy/setability to within 0.1 second	USML III; WA ML 3	Accurate electronic clock technology	Ability to test fuze accuracy and reliability.	None identified
High-explosive formulations	Precisely tailored energetic properties to prevent ignition	USML V; WA ML 8	Although standard formulations are usable, formulations to reduce potential aerosol ignition are desirable.	Measures of explosive stability, oxygen balance desirable.	Explosive dissemination pattern prediction
Energetic materials	Low-temperature burning energetic materials capable of vaporization/condensation or ablative dissemination of solid agents	USML V; WA ML 8; WA Cat 1C; CCL Cat 1C	Energetics with sufficiently low and controllable burning temperatures that do not destroy the material being disseminated.	Measurement of energetic mix burning temperatures.	Dissemination effectiveness predictive models

(cont'd)

Table 4.2-1. Dissemination, Dispersion, and Weapons Testing Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
On-board sensors for sequencing and initiation of CW warheads	Radar or radio proximity sensors for reliable measurement of altitudes from 50 to 100 meters. Guidance integrated fuzing. Nonenergetic electro-mechanical mechanisms for warhead control and initiation.	USML XI, XII; WA ML 11, 15	None identified	Specially designed ground approach or terrain return simulators	HOB measurement and detection algorithms and logic algorithms for ECCM or terrain feature analysis
Aerodynamic dissemination	Nonexplosive dispersion of CW agents in a line source in the atmosphere	USML XIV; WA ML 7	Compatible thixotropic additives for control of particle size	Rheogoniometer for measurement of dynamic rheological properties of batches	Dissemination effectiveness predictive models
Submunition dispersion	Capability to produce and disperse agent filled sub-munitions	USML IV; WA ML 4	None identified	Corrosion/leak-resistant casings for sub-munitions. Sub-munition fill capability for missile warheads.	Dissemination effectiveness predictive models
Prediction/sensing of micro-meteorology	Ability to predict wind velocity and direction in a target area	CCL EAR 99; USML XIV, XXI	None identified	Deployable micro-meteorological sensors	Linkage of sensor data to weapons system to control employment
De-agglomeration of particles	Ability to have majority of pre-ground solid particles in the inhalable range	USML XIV; WA ML 7	Effective (probably item-specific) de-agglomerant	Reliable particle size measurement	None identified
Dosage/Area measurement	Ability for reasonable measurement of dissemination effectiveness	USML XIV; WA ML 7	None identified	Techniques for measurement of aerosol concentrations versus time and/or ground depositions over a broad area	Software to translate data to concentration isopleths
Fuzzy logic for unmanned aircraft	Use of fuzzy logic in conjunction with on-site micro-meteorological data to optimize dissemination performance	WA ML 21; USML XXI	None identified	None identified	Fuzzy programs to rapidly adjust delivery to prevailing meteorological conditions

Table 4.2-2. Dissemination, Dispersion, and Weapons Testing Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
Projectile cases for CW agents	Acquiring/producing fillable/fireable and leakproof munition casings	Bombs, projectiles, submunitions, warheads	None identified
Warheads for CW missile systems	Producing casings for either bulk liquid or submunitions capable of appropriate opening for dissemination.	Missiles	None identified
Electronic time fuzes	Producibility	Conventional, biological and chemical warheads	Radar fuzes, proximity fuzes
High explosive formulations	Ability to cast stable explosives for weapon environments.	All munitions systems	None identified
Energetic materials	Low-temperature burning energetic materials capable of vaporization/ condensation or ablative dissemination of solid agents.	All munitions systems	None identified; many energetics available
On-board sensors for sequencing and initiation of CW warheads	Effects of initiation mechanism on agent	Technology common to conventional cannister weapons and strategic/ tactical nuclear weapons	Delivery from manned aircraft Surface burst/contact sensor
Aerodynamic dissemination	Nonexplosive dissemination of CW agents	Line source delivery of CW agents	Different delivery system
Submunition dispersion	Fuzing, filling	CW agent delivery	Bombs, warheads
Prediction/sensing of micro-meteorology	Data collection	Prediction of CW effects	On-site observers
De-agglomeration of particles	Keeping particles in inhalable size	Dissemination of CW agent	None identified
Dosage/Area measurement	Detection, collection	Contamination avoidance, command and control	Use animals
Fuzzy logic for unmanned aircraft	Computational ability	Delivery of CW agent	Normal logic

SECTION 4.3—DETECTION, WARNING, AND IDENTIFICATION

OVERVIEW

Because many toxic chemicals act quickly, rapid detection is needed to prevent lethal or incapacitating results from unwanted exposure. This subsection covers a variety of technologies that can be used to detect CW agents. Sample collection, sample processing, and information processing are vital to enable identification and warning of chemical exposure.

Detection can be accomplished at a designated location (point detection) or at a distance (standoff detection). No single fielded sensor detects all chemical agents of interest. Standoff detection is particularly difficult for low volatility agents (e.g., either U.S. or Russian forms of VX). Sensitivity of a detector is crucial to detecting lethal concentrations. Equipment must be reliable, provide identification quickly with a low false alarm rate and high accuracy, and be integrated into an alarm system so that warning can be distributed and proper action taken. Unknown factors can include location, persistence, and intensity of the agent. These are critical parameters for command decisions. Figure 4.3-1 shows a U.S. Chemical Agent Monitor (CAM). Detection, warning, and identification have an offensive CW component and are also necessary in a defensive context.

Figure 4.3-1. Chemical Agent Monitor (CAM)

Some amount of detection and warning capability is needed if a country is to develop and employ chemical weapons. When toxic chemicals are produced, detection and warning are necessary to the extent that the safety of workers is important. If storage sites are established, detection is needed to verify the integrity of the weapons and to ensure that the surrounding area does not become contaminated. These concerns can be mitigated if production occurs just before use. Even though soldiers and airmen employing chemical weapons might wear some type of protective clothing, detection is necessary to prevent inadvertent exposure and to minimize contamination. It should be noted that other countries have not considered safety to be as important as the U.S. did when it was involved in offensive CW preparation. Consequently, they may dispense with procedures that the U.S. deemed essential.

Highlights

- Detection requirements for a purely offensive posture are minimal.
- A prudent attacker must be prepared to defend against a counter-attack in kind if the CW threshold is crossed.
- Detection, warning, and identification of the employment of CW are key to implementing defensive measures.
- Detection of CW is a key aspect of CWC compliance.

Proliferators of chemical weapons would not need much detection equipment. The agent(s) being produced and used would be known. Point detectors would be sufficient to determine inadvertent leakage. Detection capability is required to know when the environment is safe for normal operations after CW has been employed.

Detection, warning, and identification are critical in a defensive role. Protection against chemical agents is available, but since wearing protective gear degrades military performance, units must not assume a protective posture until it is mandatory. Many prophylactic measures are most effective if implemented before exposure, and many therapeutics must be initiated soon after exposure. The sophistication needed depends on the technological capability of the enemy.

The detection and identification requirements in a defensive posture are much more difficult to meet than those required for offensive operations. Detection, warning, and identification systems are further stressed because the time, place, amount, and type of agent used are determined by the attacker. The defender must be ready for anything at any time and in any amount.

Historically, detection of ground and surface contamination has depended on a color change on special paper that was exposed to an agent. Another method was a color change that occurred when air was drawn through tubes with special dye chemicals on a substrate. Special analytical kits were used to determine the presence of chemical agents in water. Various technologies are used in automatic detectors. All of them indicate the presence of an agent in one location. A number of detectors are being developed to provide standoff capability. Figure 4.3-2 shows the U.S. Remote Sensing Chemical Agent Alarm (RSCAAL), which is designed to detect nerve and vesicant agent clouds at up to 5 km. If an agent can be detected at a sufficient distance, measures can be taken to avoid the contamination and the need to wear protective clothing.

Figure 4.3-2. RSCAAL

RATIONALE (See Table 4.3-1)

To prevent unnecessary casualties during production, transport, storage, and employment, a proliferant might need only be able to detect those agents that are being developed. A number of technologies could be used for this purpose, although only point detectors would suffice, since the location and identity would already be known. Warning would be quite simple. A prudent attacker, however, must be prepared for a retaliatory attack by an adversary. In this case, the agent to be expected might not be known. Identification and warning would be critical to taking proper defensive measures.

The ability to detect and identify toxic agents and provide warning to forces is essential for operating in a chemical environment. Early detection and warning provide situational awareness to allow military forces to avoid or reduce the threat. If exposure cannot be avoided, troops must don protective clothing. Military forces also must know when contamination has been reduced to a level that permits normal operations. Knowledge of areas of residual contamination is important as well.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 4.0-2)

A number of Western countries (Canada, France, Germany, the UK, and the United States) have significant capability in sensor technology. Russia and Israel also are well advanced in this field. At least 18 countries have some type of chemical detector in their armed forces. Countries among the 18 include China, Finland, Hungary, Iran, Iraq, Libya, the Netherlands, North Korea, the Czech Republic, and South Africa.

Table 4.3-1. Detection, Warning, and Identification Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Ion Mobility Spectrometry (IMS)	Detect level 0.05–1.0 mg/m^3 of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B	Radioactive materials in some systems	None identified	Spectral data base
Mass Spectrometry-mass spectrometry (MS-MS)	Detect level 0.1–100 picograms of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B, 3A	None identified	Miniaturization and ruggedizing of current technology required	Spectral data base
Passive Infrared (IR)	Detect level @1,000 m ~100 mg/m^3 of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B, 6A	None identified	Database development	Requires data base of emission patterns
Wet chemistry	Detect >1.0 mg of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B	None identified	None identified	None identified
Enzymatic reactions	Detect level <0.1 mg of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B	Enzyme (aceto-cholinesterase) substrate	None identified	None identified
Gas phase ion chemistry	Detect levels <1.0 mg of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B	None identified	Ion source	None identified
Gas Chromatography (GC)-IMS	Detect level 0.1–1.0 mg/m^3 of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B, 3A	Carrier gas	None identified	Spectral data base. Retention time indices.

(cont'd)

Table 4.3-1. Detection, Warning, and Identification Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
GC-Mass Spectrometry (MS)	Detect level 1– 100 picograms of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B, 3A	Carrier gas	None identified	Spectral data base Retention time indices
GC-Flame Photometric Detector (FPD)-Flame Ionization Detector (FID)	Detect level 10– 1,000 picograms of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B	Carrier gas	None identified	Retention time indices
Transverse Field Compensation (TFC)-IMS	Detect level 0.001– 0.01 mg/m^3 of CW agent	WA ML 7; WA Cat IA; AG List; USML XIV; CCL Cat 2B	Radioactive materials	None identified	Spectral data base
Surface Acoustic Wave (SAW) Crystal Arrays	Detect level 0.01–1.0 mg of CW agent	WA ML 7; WA Cat IA, 3A; AG List; USML XIV; CCL Cat 2B, 3A	Polymer coatings	None identified	Signal patterns of arrays
Absorption LIDAR	Detect levels of 1 mg/m^3 of CW agent	WA ML 7; WA Cat IA, 6A; AG List; USML XIV; CCL Cat 2B, 6A	None identified	None identified	Spectral data base
Scattering LIDAR	Detect levels above 1 mg/m^3 of CW agent	WA ML 7; WA Cat IA, 6A; AG List; USML XIV; CCL Cat 2B, 6A	None identified	None identified	Spectral data base

(cont'd)

Table 4.3-1. Detection, Warning, and Identification Technology Parameters (cont'd)

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Information Processing (e.g., data reduction, information transfer, sensor multiplexing, decision making	Any capability is a concern	CCL EAR 99	None identified	Multiplexed system for detection of CW agents	Adaptations of existing systems.
Sample Processing (e.g., concentration)	Any capability is a concern	WA ML 7; WA Cat IA; AG List; USML XIV; CCL 2B	None identified	Analytical chemistry equipment	Spectral recognition algorithms
Remote liquid particulate sensing	Detect levels above 1 mg/m^3	WA ML 7; WA Cat IA; AG List; USML XIV; CCL 2B	None identified	None identified	Emission data base
Remote solid particulate sensing	Detect levels above 1 mg/m^3	WA ML 7; WA Cat IA; AG List; USML XIV; CCL 2B	None identified	Database development	Requires database of emissions

Table 4.3-2. Detection, Warning, and Identification Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
Ion Mobility Spectrometry (IMS)	Replacement of radioactive elements	Point alarm	Use another detection technology
Mass Spectrometry-mass spectrometry (MS-MS)	Power requirement	Verification	Use another detection technology
Passive Infrared (IR)	Potential interference of atmospheric pollutants; identification of specific substances; limited to relatively volatile material; atmospheric transmission window; signal processor intensive	Remote detection of chemical agents	Use another detection technology
Wet chemistry	Requires significant servicing; environmental limitations on reactants	Point alarm	Use a live animal
Enzymatic reactions	Requires individual processing and interpretation; sensitivity of living substrates to environment	Point alarm	Use another detection technology
Gas phase ion chemistry	Source of ionization; analysis of products	Point alarm	Use another detection technology
Gas Chromatography (GC)-IMS	Electric requirement	Point alarm	Use another detection technology
GC-Mass Spectrometry (MS)	Electric requirement "Long" (1–20 min) response time	Point alarm	Use another detection technology
GC-Flame Photometric Detector (FPD)-Flame Ionization Detector (FID)	Electric requirement "Long" (2–10 min) response time	Point alarm	Use another detection technology
Transverse Field Compensation (TFC)-IMS	Electric requirement	Point alarm	Use another detection technology
Surface Acoustic Wave (SAW) Crystal Arrays	"Long" (0.5–5 min) response time	Point alarm	Use another detection technology
Absorption LIDAR	Substance dependent sensitivity; atmospheric transmission window	Remote sensing	Use another detection technology
Scattering LIDAR	Substance dependent sensitivity	Remote sensing	Use another detection technology
Information Processing (e.g., data reduction, information transfer, sensor multiplexing, decision making	Availability/preparation of comprehensive data base on known and potential toxic material	Areas where comparison of spectral and/or other data is required for detection/identification	Manual data analysis

(cont'd)

Table 4.3-2. Detection, Warning, and Identification Reference Data (cont'd)

Technology	Technical Issues	Military Applications	Alternative Technologies
Sample Processing (e.g., concentration)	Differentiation of samples from background	All areas of agent sensing	None identified
Remote liquid particulate sensing	Several agents (e.g., VX) are of very low volatility and provide little material for sensing	Remote sensing	None identified
Remote solid particulate sensing	Highly toxic particulates cannot be detected by current remote methods	Remote sensing	None identified

SECTION 4.4—CHEMICAL DEFENSE SYSTEMS

OVERVIEW

Chemical defense includes individual and collective protection and decontamination. The goal of individual and collective protection is to use clothing ensembles and respirators as well as collective filtration systems and shelters to insulate forces from chemical agents. Decontamination is essential to return personnel and equipment to normal operating conditions. Technologies for these types of equipment are included in this subsection.

Masks protect the respiratory system by preventing the inhalation of toxic chemical vapors and aerosols. They protect eyes and face from direct contact with chemical agents as well. Important considerations in mask design are the ability to don the mask and hood quickly, communications, respiration, performance degradation, and the ability to consume fluids while the mask is in place. Masks must be compatible with operational missions and equipment (e.g., night vision goggles). Ideally, protective clothing (garments, gloves, and boots) should provide protection from contact with chemical agents as well as flame protection, with a minimum amount of heat stress. Ensembles must be durable and able to be laundered and decontaminated. Protective equipment reduces the efficiency of the person wearing it.

Collective protection enables groups to work in a toxic-free environment in tents, vehicles, or special shelters. Efforts are aimed at making systems mobile and easy to erect. Air supplied to shelters is purified in much the same way as it is for individual masks.

Shelf life of protective equipment is a concern to all users. Periodic inspections are necessary to ensure readiness.

Decontamination removes toxic substances or renders them harmless. Individuals and equipment must be decontaminated. Depending on the particular agent, CW agents can be washed and rinsed away, evaporated, absorbed, or removed by heat treatment.

There is medical treatment available to offset the effects of chemical weapons. Atropine and 2-PAM chloride can be administered upon suspicion of exposure to a nerve agent. Atropine is an anticholinergic agent. It blocks the action of acetylcholine (a nerve transmitter substance), preventing it from stimulating nerves. 2-PAM chloride is anoxime, which increases the effectiveness of drug therapy in poisoning by some—but not all—cholinesterase inhibitors. Atropine and 2-PAM chloride only work to a limited degree with refractive nerve agents such as GD. Their administration when an exposure has not occurred can be harmful. Diazepam (more commonly known as Valium) is used as an anticonvulsant once an individual exhibits incapacitating symptoms of nerve agent exposure. The carbamate pyridostigmine, given in a dose of 30 mg every 8 hours, can be used as a pretreatment for nerve agent exposure.

Highlights

- Masks and protective clothing are needed to defend against many toxic chemicals.
- Reduction in combat efficiency from wearing protective gear is estimated to be up to 50 percent.
- Proliferators may not provide the same measure of protection that is afforded U.S. troops.
- Training and protection reduce the effectiveness of chemical weapons.

Without appropriate chemical defenses, operations may have to be limited. Forces could be required to remain covered until the threat of further exposure is reduced. This could be mission threatening if persistent agents are encountered. An alternative is to avoid contamination. To do this, detection equipment must be integrated with a command and control system to ensure an alarm is disseminated.

In chemical warfare, effective chemical defense measures can greatly limit the damage inflicted by a chemical attack. In World War I the gas mask had a dramatic effect in limiting the significance of chemical weapons. Developments since then (improved masks, protective clothing, detectors, and training) have further widened the margin of protection. Collective protection takes defensive measures one step further by providing a toxic-free environment for group functions such as command centers and medical facilities. Since World War I, chemical warfare has only been used against those entirely lacking or highly deficient in protective equipment. Some suggest that chemical defense acts as a deterrent to the initiation of chemical warfare because there is less incentive to attack a well-protected force. World War II is cited as an example of this theory, since both sides were well equipped for chemical defense and neither side used chemical weapons. Others suggest that equivalent offensive capability is the real deterrent. While protective clothing can reduce the effects of CW, its use poses other problems.

Figure 4.4-1. Joint Service Lightweight Integrated Suit Technology (JSLIST)

The wearing of individual protective equipment can hinder performance by interfering with vision, communication, and dexterity. High ambient temperatures are particularly devastating to those required to don protective clothing. With training, many of the negative effects can be minimized. Overheating, however, is difficult to overcome. In hot weather, full protective gear is very burdensome. Even the threat of agents can dictate the donning of gear. Commanders must then consider limiting the duration of operations or elect to compromise the protection afforded by individual gear. Figure 4.4-1 shows the newest U.S. protective clothing.

Although the CWC prohibits the development, production, possession, and transfer of chemical weapons, it places no restraint on chemical defensive measures. The Convention ensures the rights of parties to maintain chemical defense programs and grants parties the right to "...participate in, the fullest possible exchange of equipment, material, and scientific and technological information concerning means of protection against chemical weapons."

Chemical defense systems are needed by both an attacker and a defender. An offensive unit needs to limit the number of casualties caused by inadvertent exposure. In addition, troops must be prepared for a retaliatory strike once chemical agents have been used. Since the attacker chooses the time, place, extent, and duration of an attack, defensive measures by the attacker can be planned accordingly. The extent of defensive equipment needed by a proliferant is dictated primarily by the value the nation places on human life and well-being of its forces. Other factors include potential adversaries, extent of CW use expected, quality of munitions and sealing techniques, and proficiency of both military and civilian populations obtained through training.

RATIONALE (See Table 4.4-1)

Even proliferants must provide some amount of protection for their people if they are to prevent casualties during production, storage, transport, and employment of chemical weapons. Often rogue states include defensive training for their ground forces. That is not to say that protection must or will be supplied according to U.S. standards. In World War II, the Soviets were reported to have filled chemical shells in the open with no protection. When workers died, they were replaced.

If a defensive posture is developed, individual protection, decontamination, and collective protection could be part of the program. Military requirements are much more stringent than commercial applications which deal with known substances. Ground, air, and naval forces are all subject to attack with unknown agents and must be protected. A robust defensive capability not only protects troops but could act as a deterrent against a chemical-capable adversary.

Technologies in this section can enhance chemical protection for troops. If contamination is unavoidable, protective clothing enables an individual to continue operations in a chemical environment. Collective protection is important for providing a safe and contamination-free work area and rest/relief facilities. A key use of collective protection is in medical facilities.

FOREIGN TECHNOLOGY ASSESSMENT (See Figure 4.0-2)

Numerous countries produce chemical protective gear. Production of masks is the most common, including masks for civilians (as seen in Israel during Operation Desert Storm), although limited shelf life remains a problem. Many NATO and former Warsaw Pact countries as well as Middle East and Asian states produce protective clothing. Only a few manufacture aircraft respiratory equipment: Canada, Norway, Russia, and the UK. A number of countries have developed collective protection for shelters: Finland, France, Israel, Sweden, Switzerland, and the UK. In addition, Russia has fielded and maintains a substantial inventory of collective protection systems for a wide variety of vehicles and shelters.

Since 1990 North Korea has placed a high priority on military and civilian chemical defense readiness. Training in a chemical environment is mandatory and an integral part of armed forces training. Pyongyang is attempting to equip all forces, including its reserves, with full protective gear. In addition, it has directed that the entire population be issued gas masks. Iran has increased defensive chemical warfare training in the last few years and is making efforts to buy foreign equipment.

Table 4.4-1. Chemical Defense Systems Technology Parameters

Technology	Sufficient Technology Level	Export Control Reference	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters
Production and design technology for protective masks	Any type of vapor and aerosol protection	WA ML 7; WA Cat 1E; USML X	Butyl rubber; silicone rubber; plastics	Simulated agents; leakage testers; mannequin-face model for mask and suit design; particle-size analysis equipment.	Software for generating facial contours
Production and design technology for protective clothing	Any type of vapor and aerosol protection	WA ML 7; WA Cat 1E; USML X	Charcoal activated cloth; semipermeable membranes; polymers	Simulated agents; particle-size analysis equipment; testing methodology	None identified
Absorption technology for collective protection	Any type of vapor and aerosol protection	WA ML 7; USML XIV;	Impregnated charcoal filters; polyethylene; fluoropolymer/ aramid laminate	Simulated agents; particle-size analysis equipment	None identified
Nonaqueous decon-tamination technology	Ability to decontaminate to mission essential levels	USML XIV; WA ML 7	None identified	None identified	None identified
Aqueous decontamina-tion technology	Ability to decontaminate to mission essential levels	USML XIV; WA ML 7	Sufficient water supply	None identified	None identified
Medical prophylaxis technologies	Ability to protect mission essential personnel	USML XIV; WA ML 7	None identified	None identified	None identified
Therapeutic technologies	Ability to protect mission essential personnel	USML XIV; WA ML 7	Chloromide S-330; atropine/obidoxime chloride (CAS 114-90-9)	None identified	None identified

Table 4.4-2. Chemical Defense Systems Reference Data

Technology	Technical Issues	Military Applications	Alternative Technologies
Production and design technology for protective masks	Communications (microphone pass-through); respiration (air management); eye protection; composite eye lens retention system; anthropometrics; performance degradation; ability to consume fluids; protect from unknowns; shelf life	Aircrew masks; protective masks	Technologies that enable contamination avoidance
Production and design technology for protective clothing	Integration with hood/mask; closure technology; performance degradation; ability to consume fluids; limited life span; protect from unknown; environmental considerations; shelf life	Individual protection	Technologies that enable contamination avoidance
Absorption technology for collective protection	Affordable; deployable; adaptable to structure; modification to deal with filter penetrants; protection from unknown; charcoal for most organic materials	Collective protection	Individual protection technologies; technologies that enable contamination avoidance
Nonaqueous decontamination technology	Volume of toxic agent; time required; adaptability to unknown agents; disposal of agent; identification of what needs to be decontaminated; identification of decrease of toxicity to allowable level; solubility of agent; corrosiveness on material; sensitivity of electrical components	Reduce contamination to allow military operations	Weather (time); aqueous decontamination; technologies that enable contamination avoidance
Aqueous decontamination technology	Volume of toxic agent; time required; adaptability to unknown agents; disposal of agent; identification of what needs to be decontaminated; identification of decrease of toxicity to allowable level; solubility of agent; corrosiveness on material; sensitivity of electrical components	Reduce contamination to allow military operations	Weather (time); nonaqueous decontamination; technologies that enable contamination avoidance
Medical prophylaxis technologies	Efficacy of prophylaxis; pre- vs. post-exposure treatment; side effects; storage; application synergism.	Reduce casualties; reconstitute forces	Therapeutics; individual and collective protection technologies; technologies that enable contamination avoidance
Therapeutic technologies	Side effects; response time	Reduce casualties; reconstitute forces	Technologies that enable contamination avoidance