THE CHEMICAL AND BIOLOGICAL WARFARE THREAT

Contents

Chemical Warfare: A Tutorial

Introduction

Chemical warfare (CW) can be considered the military use of toxic substances such that the chemical effects of these substances on exposed personnel result in incapacitation or death. It is the impact of chemical effects instead of physical effects (such as blast and heat) that distinguishes chemical weapons from conventional weapons, even though both contain chemicals. In many cases in the Third World, there can be considerable confusion as to what is a chemical weapon and what is not. Some countries consider smoke, flame, incendiary, or riot control weapons to be chemical weapons and label them as such; in addition, conventional weapons can inflict casualties resembling those caused by chemical weapons.

Generally speaking, a chemical weapon is comprised of two main parts: the agent and a means to deliver it. Optimally, the delivery system disseminates the agent—most often a liquid—as a cloud of fine droplets, known as an aerosol. This permits the highly toxic agents to cover a relatively broad amount of territory evenly and efficiently.

Chemical warfare, as we know it, began in 1915 when Germany disseminated large clouds of chlorine, a choking agent, on French troops. Allied forces eventually responded in kind, resulting in continuous escalation by both sides until the end of the war. By the time the Armistice was signed in November 1918, well over 1 million soldiers and civilians had been injured by chemical weapons and nearly 100,000 had died. Chemical weapons continued to be used sporadically after World War I—including Italian use in Ethiopia in 1937 and Egyptian use in Yemen during the mid-1960s—but large-scale use of chemical weapons did not resume until Iraq began using them against Iran in 1983. It was this use that underscored the threat of CW proliferation among Third World countries and highlighted the need to control the spread of chemical weapons.

CW Agents

Chemical warfare agents can be classified on the basis of a number of physical and chemical properties. These properties, which underlie the advantages and disadvantages of each agent, are summarized below.

Lethality is a way of classifying CW agents to be either lethal or nonlethal, but there is not always a clear distinction. Lethal agents are designed primarily to cause fatalities under battlefield conditions, although sublethal doses will cause incapacitation. Nonlethal agents are designed primarily to incapacitate or injure but can kill in large enough doses.

Mode of action indicates by which of several routes CW agents and other toxic chemicals affect living organisms. From a CW standpoint, the most useful routes of exposure are passive ones, such as inhalation and percutaneous means. An agent that acts via inhalation damages the lungs or passes rapidly into the bloodstream when breathed in, while an agent that acts percutaneously damages (or enters the body through) the skin, eyes, or mucous membranes. Less useful on the battlefield but still valid for terrorist purposes are poisons that act orally—by damaging the digestive system or passing into the bloodstream when swallowed—and intravenously, by passing directly into the bloodstream.

Speed of action is a measure of the delay between exposure and effect. Rapid-acting agents can cause symptoms to appear almost instantaneously and might cause fatalities in as little as a few minutes. Slow-acting agents can take days before causing the first symptoms and might take weeks or months before fatalities occur. In general, though, higher doses increase the rate of action.

Toxicity is a measure of the quantity of a substance required to achieve a given effect. CW agents are really just highly toxic compounds that work via inhalation or skin contact. For example, 3,200 milligrams (mg) of the World War I choking agent phosgene per cubic meter of air will kill 50 percent of a test population of humans breathing this mixture. Only 70 mg of the nerve agent sarin—45 times less than phosgene—is required to cause the same fatality rate. The nerve agent VX is even more toxic; just 10 mg on the skin will kill the average adult male. One gallon of VX contains 382,000 such doses. By definition, if the VX is evenly applied at this dosage, 50 percent—or 191,000 people—will die as a result, with the remaining 191,000 becoming seriously ill. This is not really a practical example because, in battlefield use, it is impossible to apply such precise dosages; only a small part of the agent comes into contact with victims. Therefore, such a high casualty rate will never be achieved in practice. However, this example serves to demonstrate how highly toxic some agents really are.

Persistency is a measure of the length of time an agent remains a hazard on the battlefield. Nonpersistent agents tend to be rather volatile and evaporate quickly; these dissipate within a few minutes to about one hour. Semipersistent agents generally linger for several hours to one day. Persistent agents, which tend to be rather thick and oily, can last for several days to a few weeks. Agents can also be "thickened" to increase persistency by adding one of a variety of viscous materials. The mixing of thickeners with soman, for example, will increase the persistency of soman. However, the actual length of time an agent remains a hazard varies widely according to the environment (soil, vegetation, and so forth) and meteorological conditions (temperature, wind speed, atmospheric stability, moisture, sunlight). Just as a puddle of water evaporates more quickly on a hot, sunny, breezy July afternoon than on a cool, foggy, calm December morning, CW agents will dissipate more rapidly when exposed to high temperatures and wind speeds and an unstable atmosphere.

State refers to the physical form of the agent. CW agents can be any of the three basic states of matter—solid, liquid, or gas—but most are liquids. Thus, the terms "nerve gas," "mustard gas," and "poison gas" are misnomers. These misnomers stem from the dissemination of liquid agents as aerosol or vapor clouds, which act like gases.

CW Agents and Field Employment

In general, the amount of CW agent delivered determines the extent of contamination and the number of casualties. A rough rule of thumb is that 1 ton (or about four 55-gallon drums) of agent is enough to effectively contaminate 1 square mile of territory if properly disseminated. The number of resultant casualties depends on the number of people in the contaminated area, length of warning, and degree of protection, as well as the persistency and lethality of the agent used. The persistency of a specific agent (length of time it remains effective) varies depending on the type of munition used and the weather conditions. In all cases, given sublethal doses of an agent, incapacitation will occur to varying degrees.

First-Generation Agents

Choking agents are the oldest CW agents. This class of agents includes *chlorine* and *phosgene*, both of which were used in World War I. In sufficient concentrations, their corrosive effect on the respiratory system results in pulmonary edema, filling the lungs with fluid and choking the victim. Phosgene is more effective than chlorine because it is slowly hydrolyzed by the water in the lining of the lungs, forming hydrochloric acid, which rapidly destroys the tissue.

These agents are heavy gases that remain near ground level and tend to fill depressions such as foxholes and trenches. Because they are gases, they are nonpersistent and dissipate rapidly in a breeze. As a result, these are among the least effective traditional CW agents. They are useful for creating a short-term respiratory hazard on terrain that is to be quickly occupied.

Blood agents are absorbed into the body primarily by breathing. They prevent the normal utilization of oxygen by the cells and cause rapid damage to body tissues. Blood agents such as *hydrogen cyanide (AC)* and *cyanogen chloride (CK)* are highly volatile and in the gaseous state dissipate rapidly in air. Because of their high volatility, these agents are most effective when surprise can be achieved against troops who do not have masks or who are poorly trained in mask discipline. In addition, blood agents are ideally suited for use on terrain that the user hopes to occupy within a short time. Blood agents rapidly degrade a mask filter's effectiveness. Therefore, these agents could also be used to defeat a mask's protective capabilities when combined with other agents.

Blister (vesicant) agents are primarily used to cause medical casualties. These agents may also be used to restrict use of terrain, to slow movements, and to hamper use of materiel and installations. Blister agents affect the eyes and lungs and blister the skin. *Sulfur mustard, nitrogen mustard,* and *lewisite* are examples of blister agents. Most blister agents are insidious in action; there is little or no pain at the time of exposure except with lewisite, which causes immediate pain on contact.

Sulfur mustard is considered by some to be the ideal CW agent. It presents both a respiratory and a percutaneous hazard, forcing military personnel to don not only gas masks but also cumbersome protective overgarments—seriously degrading their ability to function. Mustard is persistent and presents a long-term hazard, further hindering victims by forcing them to decontaminate. Being based on old technology, it is simple to produce, even by Third World standards. Moreover, it causes large numbers of long-term, debilitating injuries, whose treatment can easily overburden an enemy's war effort.

From a CW perspective, an advantage of mustard over lewisite is that the latter hydrolyzes very rapidly upon exposure to atmospheric moisture to form a nonvolatile solid. This conversion lowers the vapor hazard from contaminated terrain and decreases the penetration of the agent through clothing. Lewisite is less persistent than mustard; however, the persistency of both is limited under humid conditions.

Second-Generation Agents

G-series nerve agents, including *tabun (GA), sarin (GB), soman (GD),* and *GF,* are members of a class of compounds that are more lethal and quicker acting than mustard. They are organophosphorus compounds that inhibit action of the enzyme acetylcholinesterase. These agents are similar to many pesticides and, in fact, were accidentally discovered in the 1930s by German chemists seeking new types of pesticides.

G-series agents act rapidly (within seconds of exposure) and may be absorbed through the skin or the respiratory tract. However, some of these agents, particularly GA and GB, tend to be relatively nonpersistent and consequently present less of a skin hazard than a vapor hazard. In sufficient concentration, the ultimate effect of these agents is paralysis of the respiratory musculature and subsequent death. Exposure to a lethal dose may cause death in as little as several minutes. These less persistent agents are used to cause immediate casualties and to create a short-term respiratory hazard on the battlefield. Persistent G-series nerve agents such as GS and GF would present more of a skin hazard.

Third-Generation Agents

V-series nerve agents, including *VE, VG, VM, VS,* and *VX,* are compounds similar to, but more advanced than, G-series nerve agents. Developed in the 1950s by the British, these agents tend to be more toxic and more persistent than G-agents. They present a greater skin hazard and are used to create long-term contamination of territory.

Nonlethal Agents

Tear gas agents fall under the broader category of riot control agents. They are not considered by the US Government to be CW agents because they are nonlethal in all but the highest concentrations.

Examples of this type of agent include *orthochlorobenzylidene malononitrile (CS), chloroacetophenone (CN), chloropicrin (PS),* and *bromobenzyl cyanide (BBC).* These agents are highly irritating, particularly to the eyes and respiratory tract, and cause extreme discomfort. Symptoms occur almost immediately upon exposure and generally disappear shortly after exposure ceases.

In military situations, tear gas agents are used to temporarily reduce the effectiveness of enemy personnel. In tactical operations, they can be used to penetrate fortified positions and flush out the enemy. Also, these agents are useful for disrupting "human wave" assaults by breaking up formations and destroying the momentum of the attack. Because tear gas agents are nonlethal, they can be used near friendly troops without risking casualties; thus, their use is more flexible than with conventional CW agents.

Vomiting agents are often considered to be riot control agents because, under field conditions, they cause great discomfort but rarely serious injury or death. Characteristic agents include *adamsite (DM)* and *diphenyl chloroarsine (DA).* In addition to causing vomiting, these arsenic-based agents may also irritate the eyes and respiratory system.

The action of vomiting agents may make it impossible to put on, or continue wearing, a protective mask. Therefore, in military situations, vomiting agents may be used in conjunction with lethal CW agents to increase casualties. They may also be used by themselves in proximity to friendly troops and in other situations well-suited for tear gas agents.

Psychochemicals, also considered incapacitants, include hallucinogenic compounds such as *lysergic acid diethylamide (LSD), 3-quinuclidinyl benzilate (BZ),* and *benactyzine.* These agents alter the nervous system, thereby causing visual and aural hallucinations, a sense of unreality, and changes in the thought processes and behavior. Psychochemicals are generally characterized by a slightly delayed onset of symptoms and by persistence of symptoms for a period greatly exceeding exposure time.

The advantage of psychochemicals is their ability to inactivate both civilian and military personnel for a relatively short period with essentially no fatalities. Thus, their use may prove advantageous in areas with friendly populations. One drawback, however, is that the effects of many of these agents are unpredictable.

Chemical Weapons

There are many different ways to disseminate CW agents. Most common are the free-flight munitions that are fired at or dropped on a target. These can be weaponized in unitary or binary form, and the larger munitions can contain submunitions. It is also possible to disseminate agent from a spray tank attached to an aircraft or from a ground-based aerosol generator.

Most conventional munitions can be modified to deliver lethal or nonlethal chemical agents. Typical chemical munitions include:

- Aerial bombs.
- Artillery rockets.
- Artillery shells.
- Grenades.
- Mines.
- Missile warheads.
- Mortar rounds.

These normally contain burster charges surrounded by bulk-fill agent. The burster ruptures the munition and causes the agent to be disseminated as a stream or cloud of small droplets.

Air- or ground-based aerosol generators can be used for more controlled dissemination of CW agents. A spray tank can be used to disseminate agents from aircraft, just as crop dusters are used to spread insecticides. Similarly, the same type of ground-based aerosol generators used to disseminate pesticides can be used for CW purposes. One drawback of these systems, however, is limited survivability during wartime.

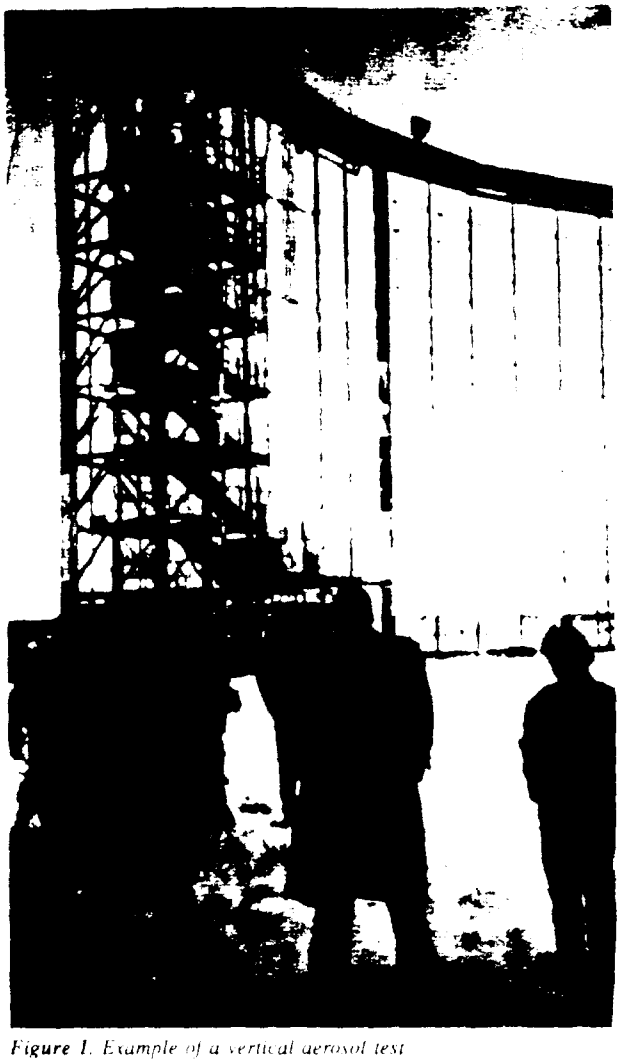


Figure 1. Example of a vertical aerosol test grid for open-air exposure

Chemical munitions usually fall into one of two categories: unitary or binary. A unitary munition contains the agent itself, while binary munitions contain two agent precursors that mix in the munition and form agent before or during flight. Unitaries are able to deliver more agent per munition, but binaries—because they contain the less toxic precursors—are safer.

CW agents can also be carried in submunitions or bomblets. The submunitions are ejected from the primary munition some distance above the ground. They land on the ground in a random pattern and detonate, covering an area larger and more evenly than with a bulk-fill munition.

Optimum fuzing can vary depending on the agent. Impact fuzing, employed in ground-burst munitions, is best used in conjunction with volatile, nonpersistent agents, which generally will dissipate if disseminated at too great an altitude. Proximity fuzing—whether based on lasers, radar, barometric pressure, or timers—is best used in conjunction with persistent agents, which can be disseminated at higher altitudes and still reach the target.

Production of CW Agents

Many CW agents, particularly the first-generation agents, are simple to produce. They are often based on technology that is at least 80 years old and sometimes older, putting them well within the reach of virtually any Third World country that wants them. Newer agents, particularly the nerve agents, are more difficult to produce; however, the technology for these agents is widely available in the public domain.

In many ways, production of CW agents is like that of legitimate commercial compounds. Both involve use of standard chemical process equipment, including reactor vessels, in which production actually occurs; distillation columns and filters, where compounds are separated or purified; heat exchangers, to control temperature; and various pumps, pipes, valves, and other items that control the movement of chemicals throughout the plant. The greatest similarities occur between pesticide and nerve agent production units because these compounds are so closely related.

There are some pieces of equipment, such as those controlled by the Australia Group (see inset), that are distinct enough to warrant special consideration.[1] In particular, equipment that is exceptionally

[1] For a detailed listing of this equipment, please see table 3, General Guidelines for Identifying Dual-Use Chemical Equipment and Related Technology.

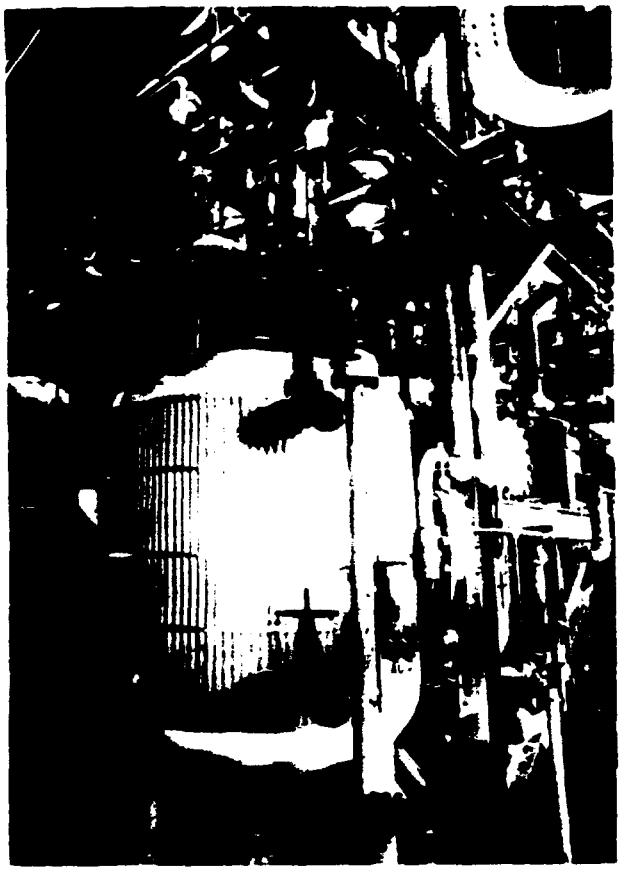


Figure 2. Chemical reactor

Figure 3. Process control equipment

resistant to corrosion—such as Hastelloy and other high-nickel alloys—has important applications in CW because of the highly corrosive compounds encountered in CW agent production. Also worthy of suspicion are double-seal pumps and other equipment designed to handle exceptionally toxic compounds.

CW Defense

There are four primary aspects of CW defense:

Protection. Potential victims need to prevent CW agents from coming into contact with the body. This is accomplished by surrounding the body with a physical barrier consisting of a gas mask, to filter air; a protective overgarment, boots, and gloves to keep agents away from the skin; and, sometimes, collective protective systems to do both. Masks usually are fitted with canisters filled with activated charcoal, which filters out CW agents as air is drawn through. Gloves and boots are almost always made of butyl rubber or a similar impermeable material that is resistant to CW agents. Some overgarments, such as those in the former Soviet Bloc countries, are impermeable as well. In contrast, Western overgarments are usually made of layers of activated charcoal sandwiched between two pieces of semipermeable fabric; these allow for ventilation.

Detection. Adequate detection is needed to ensure that troops take adequate protective measures in time. Detectors range from electronic standoff instruments to treated paper. The time needed to detect CW agents can vary considerably.

Australia Group

*The **Australia Group** is an informal organization, currently consisting of 25 nations, committed to ensuring that exports of materials and equipment from their countries do not contribute to the spread of chemical or biological weapons. The group, formed in 1984, meets biannually to:*

- *Discuss and agree on measures to control the export of CBW-relevant material and equipment.*
- *Consider effective means of implementing and enforcing export controls.*
- *Exchange information on CBW proliferation.*
- *Discuss provisions to control activities that could contribute to CBW proliferation.*
- *Expand membership in the AG to other select nations and to encourage all countries to adopt export controls on relevant materials comparable to those adopted by the AG.*

To date, Australia Group members have adopted export controls or agreed to institute controls on the following:

- *Fifty-four chemical warfare agent precursor chemicals.*
- *Dual-use processing equipment that is applicable to the manufacture of CW agents and precursor chemicals.*
- *Human, animal, and plant pathogens and toxins with potential BW applications.*
- *Dual-use biological equipment, suitable for development, production, or dissemination of BW agents.*

The embargoes on CBW-relevant material and equipment have impeded but not stopped CBW weapons proliferation. However, by continuing to focus on export controls, the Australia Group will remain a viable force in curtailing the spread of CBW weapons and will play a complimentary role to the Chemical and Biological Weapons Conventions' (CWC and BWC) goals of completely eliminating these weapons from world arsenals.

Decontamination. If equipment and personnel are exposed to a persistent agent, decontamination is needed to eliminate the hazard. Decontamination generally involves using a water-based caustic or bleach material to neutralize any agent present. Sodium hydroxide and sodium hypochlorite are two common constituents of decontaminant solutions.

Treatment. If a victim is exposed to agent, prompt medical treatment is needed to counteract the agent and limit injuries. For example, atropine is the standard antidote for nerve agent poisoning. This compound is injected into the bloodstream and often is followed by a cholinesterase reactivator, such as pralidoxime chloride (or 2-PAM chloride). In addition, pretreatments, such as pyridostigmine, can be used before an attack to limit nerve-agent-related damage.

One important factor to consider is the degradation in performance caused by CW defense. Troops wearing protective overgarments function much less effectively than troops without, leading to a reduction in the effective strength of a military unit. Thus, a military advantage can be achieved merely by threatening to use chemical weapons. In addition, the need to decontaminate—such as the presence of a persistent agent—even further reduces fighting ability.

Table 1
Chemical Warfare Agents

Agent Class	Agent	Symbol	Persistency	Rate of Action
Nerve	Tabun	GA	Low	Very rapid
	Sarin	GB	Low	Very rapid
	Soman	GD	Moderate	Very rapid
	GF	GF	Moderate	Very rapid
	VX	VX	Very high	Rapid
Blister	Sulfur mustard	H.HD	Very high	Delayed
	Nitrogen mustard	HN-1	High	Delayed
		HN-2	Moderate	Delayed
		HN-3	Very high	Delayed
	Phosgene oxime	CX	Low	Immediate
	Lewisite	L	High	Rapid
	Phenyldichloroarsine	PD	Low-moderate	Rapid
	Ethyldichloroarsine	ED	Moderate	Delayed
	Methyldichloroarsine	MD	Low	Rapid
Choking	Phosgene	CG	Low	Delayed
	Diphosgene	DP	Low	Variable
Blood	Hydrogen cyanide	AC	Low	Rapid
	Cyanogen chloride	CK	Low	Rapid
	Arsine	SA	Low	Delayed
Riot control (vomiting)	Diphenylchloroarsine	DA	Low	Rapid
	Diphenylcyanoarsine	DC	Low	Rapid
	Adamsite	DM	Low	Rapid
Riot control (tear gas)	Chloroacetophenone	CN	Low	Immediate
	Chloropicrin	PS	Low-high	Immediate
	Bromobenzylcyanide	CA	Moderate-very high	Immediate
	O-chlorobenzylidene malononitrile	CS	Low-high	Immediate
Psycho-chemicals	3-Quinuclidinyl benzilate	BZ	High	Delayed

Table 2
CW Agent Precursor Chemicals--Uses and CW Agent Equivalents

Precursor Chemical	Civil Uses	CW Agent Production	Units of Agent per Unit of Precursor[1]
1. Thiodiglycol 111-48-8	Organic synthesis	Sulfur mustard (HD)	1.3
	Carrier for dyes in textile industry		
	Lubricant additives	Sesqui mustard (Q)	1.79
	Manufacturing plastics		
2. Phosphorus oxychloride 10025-87-3	Organic synthesis	Tabun (GA)	1.05
	Plasticizers		
	Gasoline additives		
	Hydraulic fluids		
	Insecticides		
	Dopant for semiconductors grade silicon		
	Flame retardants		
3. Dimethyl methylphosphonate (DMMP) 756-79-6	Flame retardants	Sarin (GB)	1.12
		Soman (GD)	
		GF	1.45
4. Methylphosphonyl difluoride 676-99-3	Organic synthesis	Sarin (GB)	1.40
	Specific uses not identified	Soman (GD)	1.82
		GF	1.80
5. Methylphosphonyl dichloride 676-97-1	Organic synthesis	Sarin (GB)	1.05
	Specific uses not identified	Soman (GD)	1.36
		GF	1.35
6. Dimethylphosphite 868-85-9	Organic synthesis	Sarin	1.27
	Lubricant additive	Soman	1.65
		GF	1.65

[1] (Figures in parentheses are based on the use of PCl_3 as a chlorine donator in the reaction.)

Precursor Chemical	Civil Uses	CW Agent Production	Units of Agent per Unit of Precursor
7. Phosphorus trichloride 7719-12-2	Organic synthesis	VG	1.95
	Insecticides	Tabun (GA)	1.18
	Gasoline additives	Sarin (GB)	1.02
		Salt process	(0.34)
	Plasticizers	Rearrangement process	1.02
			(0.68)
	Surfactants	Soman (GD)	1.32
		Salt process	(0.44)
	Dyestuffs	Rearrangement process	1.32
			(0.88)
		GF	1.31
		Salt process	(0.44)
		Rearrangement process	1.31
			(0.87)
8. Trimethyl phosphite 121.45-9	Organic synthesis	Used to make dimethylmethyl-phosphonate (DMMP)-molecular rearrangement.	See #3
9. Thionyl chloride[2] 7719-09-7	Organic synthesis	Sarin (GB)	1.18
		Soman (GD)	1.53
		GF	1.51
		Sulfur mustard (HD)	1.34
	Chlorinating agent	Sesqui mustard (Q)	1.84
	Catalyst	Nitrogen mustard (HN-1)	0.714
	Pesticides	Nitrogen mustard (HN-2)	0.655
	Engineering plastics	Nitrogen mustard (HN-3)	1.145
10. 3-Hydroxy-1-methylpiperidine 3554-74-3	Specific uses not identified. Probably used in pharmaceutical industry.	Non-identified. Could probably be used in the synthesis of psychoactive compounds such as BZ.	
11. N,N-diisopropyl-(beta)-aminoethyl chloride 96-79-7	Organic synthesis	VX	1.64
		VS	1.72

[2] (Thionyl chloride could serve as chlorinating agent in all of these processes-other chlorinating agents could be substituted.)

Precursor Chemical	Civil Uses	CW Agent Production	Units of Agent per Unit of Precursor
12. N,N-diisopropyl-aminoethanethiol 5842-07-9	Organic synthesis	VX	1.66
		VS	1.75
13. 3-Quinuclidinol 1619-34-7	Hypotensive agent	BZ	2.65
	Probably used in synthesis of pharmaceuticals		
14. Potassium fluoride 7789-23-3	Fluorination of organic compounds	Sarin (GB)	2.41
	Cleaning and disinfecting brewery, dairy and other food processing equipment.	Soman (GD)	3.14
	Glass and porcelain manufacturing	GF	3.10
15. 2-Chloroethanol 107-07-3	Organic synthesis	Sulfur mustard (HD)	0.99
	Manufacturing of ethylene-oxide and ethylene-glycol	Sesqui mustard	0.99
		Nitrogen mustard (HN-1)	1.06
	Insecticides		
	Solvent		
16. Dimethylamine 124-40-3	Organic synthesis	Tabun (GA)	3.61
	Pharmaceuticals		
	Detergents		
	Pesticides		
	Gasoline additive		
	Missile fuels		
	Vulcanization of rubber		
17. Diethyl ethylphosphonate 78-38-6	Heavy metal extraction	Ethyl sarin (GE)	0.93
	Gasoline additive		
	Antifoam agent		
	Plasticizer		

Precursor Chemical	Civil Uses	CW Agent Production	Units of Agent per Unit of Precursor
18. Diethyl N.N-dimethyl phosphoramidate 2404-03-7	Organic synthesis	Tabun (GA)	0.90
	Specific uses not identified		
19. Diethylphosphite 762-04-9	Organic synthesis	VG	Catalyst
	Paint solvent	Sarin (GB)	1.02
	Lubricant additive	Soman (GD)	1.32
		GF	1.30
20. Dimethylamine HCl 506-59-2	Organic synthesis	Tabun (GA)	1.99
	Pharmaceuticals		
	Surfactants		
	Pesticides		
	Gasoline additives		
21. Ethylphosphonous dichloride 1498-40-4	Organic synthesis	VE	1.93
	Specific uses not identified but could be used in manufacturing of flame retardants, gas additives, pesticides, surfactants, etc.	VS	2.14
		Ethyl sarin (GE)	1.18
22. Ethylphosphonyl dichloride 1066-50-8	Organic synthesis	Ethyl sarin (GE)	2.10
	Specific uses not identified. See #21.		
23. Ethylphosphonyl difluoride 753-98-0	Organic synthesis	Ethyl sarin (GE)	2.70
	Specific uses not identified. See #21.		
24. Hydrogen fluoride 7664-39-3	Fluorinating agent in chemical reactions	Sarin (GB)	7.0
	Catalyst in alkylation and polymerization reactions	Soman (GD)	9.11
	Additives to liquid rocket fuels	Ethyl sarin (GE)	7.7
	Uranium refining	GF	9.01
25. Methyl benzilate 76-89-1	Organic synthesis	BZ	1.39
	Tranquilizers		

Precursor Chemical	Civil Uses	CW Agent Production	Units of Agent per Unit of Precursor
26. Methylphosphonous dichloride 676-83-5	Organic synthesis	VX	2.28
27. N,N-diisopropyl-(beta)-aminoethanol 96-80-0	Organic synthesis	VX	1.84
	Specific uses not identified		
28. Pinacolyl alcohol 464-07-3	Specific uses not identified	Soman (GD)	1.79
29. O-ethyl,2-diisopropyl aminoethyl methyl-phosphonate (QL) 57856-11-8	Specific uses not identified	VX	1.14
30. Triethyl phosphite 122-52-1	Organic synthesis	VG	1.62
	Plasticizers		
	Lubricant additives		
31. Arsenic trichloride 7784-34-1	Organic synthesis	Arsine	0.43
	Pharmaceuticals	Lewisite	1.14
	Insecticides		
	Ceramics	Adamsite (DM)	1.53
		Diphenylchloroarsine (DA)	1.45
32. Benzilic acid 76-93-7	Organic synthesis	BZ	1.48
33. Diethyl methylphosphonite 15715-41-0	Organic synthesis	VX	1.97
34. Dimethyl ethylphosphonate 6163-75-3	Organic synthesis	Ethyl sarin (GE)	1.12
35. Ethylphosphonous difluoride 430-78-4	Organic synthesis	VE	2.58
		Ethyl sarin (GE)	1.57
36. Methylphosphonous difluoride 753-59-3	Organic synthesis	VX	3.18
		VM	2.84
		Sarin (GB)	1.67
		Soman (GD)	2.17
		GF	2.15

Precursor Chemical	Civil Uses	CW Agent Production	Units of Agent per Unit of Precursor
37. 3-Quinuclidone 1619-34-7	Same as #13 3-quinuclidinol	BZ	2.65
38. Phosphorous pentachloride 10026-13-8	Organic synthesis	Tabun (GA)	0.78
	Pesticides		
	Plastics		
39. Pinacolone 75-97-8	Specific uses not identified	Soman (GD)	1.82
40. Potassium cyanide 151-50-8	Extraction of gold and silver from ores	Tabun (GA)	1.25
	Pesticide		
	Fumigant	Hydrogen cyanide	0.41
	Electroplating		
41. Potassium bifluoride 7789-29-9	Fluorine production	Sarin (GB)	1.79
	Catalyst in alkylation	Soman (GD)	2.33
	Treatment of coal to reduce slag formation	GF	2.31
	Fluid in silver solder		
42. Ammonium bifluoride 1341-49-7	Ceramics	Sarin (GB)	2.46
	Disinfectant for food equipment	Soman (GD)	3.20
	Electroplating	GF	3.16
	Etching glass		
43. Sodium fluoride 7681-49-4	Pesticide	Sarin (GB)	3.33
	Disinfectant	Soman (GD)	4.34
	Dental prophylaxis	GF	4.29
	Glass and steel manufacturing		
44. Sodium bifluoride 1333-83-1	Antiseptic	Sarin (GB)	2.26
	Neutralizer in laundry operations	Soman (GD)	2.94
	Tin plate production	GF	2.91

Precursor Chemical	Civil Uses	CW Agent Production	Units of Agent per Unit of Precursor
45. Sodium cyanide 143-33-9	Extraction of gold and silver from ores	Tabun (GA)	1.65
	Fumigant	Hydrogen cyanide	0.55
	Manufacturing dyes and pigments	Cyanogen chloride	1.25
	Core hardening of metals		
	Nylon production		
46. Triethanolamine 102-71-6	Organic synthesis	Nitrogen mustard (HN-3)	1.37
	Detergents		
	Cosmetics		
	Corrosion inhibitor		
	Plasticizer		
	Rubber accelerator		
47. Phosphorus pentasulfide 1314-80-3	Organic synthesis	VG	1.21
	Insecticide	VX	1.20
	Mitocides		
	Lubricant oil additives		
	Pyrotechnics		
48. Diisopropylamine 108-18-9	Organic synthesis	VX	3.65
	Specific uses not identified		
49. Diethylaminoethanol 100-37-8	Organic synthesis	VG	2.30
	Anti-corrosion compositions	VM	2.05
	Pharmaceuticals		
	Textile softeners		
50. Sodium sulfide 1313-82-2	Paper manufacturing	Sulfur mustard (HD)	2.04
	Rubber manufacturing		
	Metal refining		
	Dye manufacturing		

Precursor Chemical	Civil Uses Production	CW Agent Unit of Precursor	Units of Agent per
51. Sulfur monochloride sulfur chloride 10025-67-9	Organic synthesis	Sulfur mustard (HD)	1.18
	Pharmaceuticals		
	Sulfur dyes		
	Insecticides		
	Rubber vulcanization		
	Polymerization catalyst		
	Hardening of soft woods		
	Extraction of gold from ores		
52. Sulfur dichloride 10545-99-0	Organic synthesis	Sulfur mustard (HD)	1.54
	Rubber vulcanizing		
	Insecticides		
	Vulcanizing oils		
	Chlorinating agent		
53. Triethanolamine hydrochloride	Organic synthesis	Nitrogen mustard (HN-3)	1.10
	Insecticides		
	Surface active agents		
	Waxes, polishes		
	Textile specialties		
	Lubricants		
	Toiletries		
	Cement additive		
	Petroleum demulsifier		
	Synthetic resin		

Table 3
General Guidelines for Identifying Dual-Use Chemical Equipment and Related Technology

Storage tanks

I. Manufacturing Facilities and Equipment

1. **Reactor Vessels and Agitators** (with total volume greater than 100 liters and less than 20,000 liters)

2. **Storage Tanks, Containers, and Receivers** (with total volume greater than 100 liters)

3. **Heat Exchangers or Condensers**

4. **Distillation or Absorption Columns**

5. **Valves and Multi-Walled Piping** (multiple-seal valves, bellows-seal valves, diaphragm valves, and multi-walled piping incorporating a leak detection port)

6. **Pumps** (multiple-seal, canned-drive, magnetic drive, bellows or diaphragm pumps having a flow rate greater than 0.6 cubic meter per hour; or vacuum pumps with a flow rate greater than 5 cubic meters per hour)

Materials of construction for all surfaces of the foregoing equipment in direct contact with the chemicals being processed:

(a) Nickel or alloys with more than 40 percent nickel by weight.

(b) Alloys with more than 25 percent nickel and 20 percent chromium by weight.

(c) Fluoropolymers.

(d) Glass or glass-lined.

(e) Tantalum, titanium, zirconium, or their alloys.

(f) Graphite (for heat exchangers, pumps, and multi-walled piping only).

(g) Ceramics or ferrosilicon (for pumps only).

7. **Filling Equipment** (remotely operated)

Materials of construction for all surfaces of the foregoing equipment in direct contact with the chemicals being processed:

(a) Nickel or alloys with more than 40 percent nickel by weight.

(b) Alloys with more than 25 percent nickel and 20 percent chromium by weight.

8. **Incinerators** (with an average combustion chamber temperature greater than 1000°C)

Materials of construction for all surfaces of the foregoing equipment in direct contact with the chemicals being processed:

(a) Nickel or alloys with more than 40 percent nickel by weight.

(b) Alloys with more than 25 percent nickel and 20 percent chromium by weight.

(c) Ceramics.

Table 3 (continued)

Piping

Distillation column

Table 3 (continued)

9. Whole plants

II. Toxic Gas Monitoring Systems

1. Detectors

Toxic gas monitoring systems:

(a) Designed for continuous operation and capable of detecting chemical warfare agents and designated chemical warfare agent precursors as well as organic compounds containing phosphorus, sulfur, fluorine, chlorine at a concentration less than 0.3 milligram per cubic meter of air.

(b) Capable of detecting cholinesterase-inhibiting activity.

III. Related Technology

Technology, including licenses, directly associated with the manufacture of chemical weapons agents, their precursors, or dual-use equipment for such manufacture.

Table 4
Availability Review for Key Dual-Use Chemical Production Equipment

Item 1. Chemical process equipment constructed of Hastelloy, Monel, or another alloy with a nickel content in excess of 40 percent by weight, as follows: reactor vessels, storage tanks, and containers, heat exchangers, distillation columns, degassers, or condensers.

The chemical process equipment specified in this item is available from many countries in Europe, Asia, Latin America, Eastern Europe, and the independent republics of the former Soviet Union. These specifications encompass equipment suitable for treating certain common industrial wastes, sewage and potable water, as well as producing chemical and biological warfare agents. Following is a list of countries believed to have production capabilities for such chemical process equipment. In addition to the countries identified below, a scrap market exists from which a potential purchaser may obtain equipment.

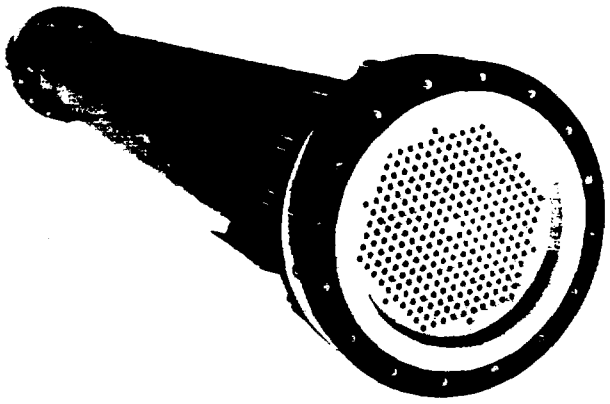
The countries listed below are believed to be capable of manufacturing the chemical process equipment described.

Reactor Vessels
United Kingdom, France, Germany, Switzerland, Hungary, China, Japan, India, Brazil, Korea, and Italy (also see Item 3 for glass-lined reactors).

Storage Tanks and Containers
Japan, Sweden, Korea, Germany, Taiwan, South Africa, Mexico, countries of former Yugoslavia, Czechoslovakia, France, and Russia and the other newly independent states.

Heat Exchangers
France, United Kingdom, China, Russia and the other newly independent states, Germany, Japan, and Singapore.

Distillation Columns
France, United Kingdom, China, Russia and the other newly independent states, Germany, and Japan.



Heat exchanger

Condensers
These are available from manufacturers worldwide, including Third World countries.

Item 2. Thermometers or other sensors encased in alloy with a nickel content in excess of 40 percent.

Thermometers or other sensors are available worldwide and, for this purpose, can be placed in a thermal well or encased as the end user specifies.

Item 3. Chemical process equipment listed in Item 1, which is *lined* with nickel, polyvinylidene fluoride, high-density polyethylene, or glass.

Chemical processing equipment with corrosion-resistant linings is also available worldwide. The principal manufacturers for nickel-lined, polyvinylidene fluoride-lined, and high-density polyethylene-lined equipment are in Western Europe and Japan.

Table 4 (continued)

For glass-lined equipment, the principal manufacturers are in Western and Eastern Europe, Japan, and South America, although China also possesses the capability to manufacture glass-lined equipment. The uses for this equipment range from the treatment of potable water, sewage, or industrial wastes to production of chemical and biological warfare agents.

Countries capable of manufacturing equipment lined with materials other than glass are identified below. For glass-lined equipment, specific companies are identified.

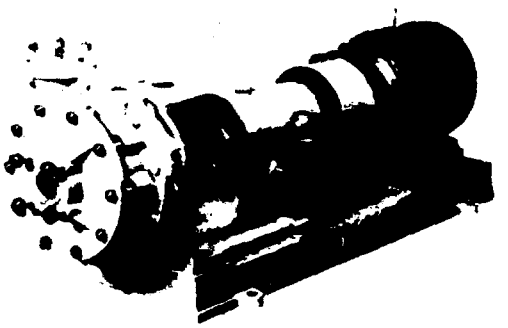
Lined With Nickel, Polyvinylidene Fluoride, and High-Density Polyethylene
Japan, Germany, and Switzerland.

Glass-Lined Reactors
United Kingdom—Canon (subsidiary of GEC); Pfaudler Balfou; **France**—DeDetrich; **Germany**—Pfaudler Werke AG; Thalle (former GDR); **Switzerland**—Estella; **Hungary**—Lampart; **Japan**—Shinko Pan Tac; Hako Sanyo; **India**—GMN Pfaudler; **Brazil**—Pfaudler S.A.; **Italy**—Tycon and Technoglass.

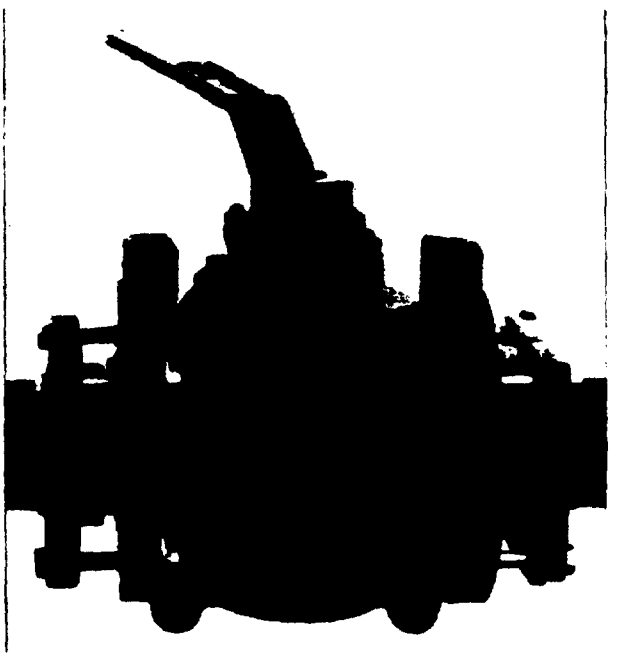
China and South Korea are capable of producing this glass-lined equipment.

Item 4. Pumps and valves (a) incorporating a body made from alloy with a nickel content in excess of 40 percent by weight, or (b) lined with nickel, or (c) otherwise designed to be utilized with fluorine or hydrogen fluorine, or organophosphorus compounds. (Note: includes double-seal, electromagnetic drive, or canned pumps; bellows or diaphragm valves meeting this specification.)

Based on a review of the manufacturers' buyer catalogs, pumps incorporating a body made from alloy with a nickel content in excess of 40 percent by weight are available from sources in Japan, Israel, and North Korea. Such pumps are also available from sources in Brazil, France, India, Israel, Taiwan, South Korea, South Africa, China, and Russia and the other newly independent states.



Pump



Valve

Valves, similarly made from nickel alloy, are also available from manufacturers in France, Israel, and Korea. Below is a list of manufacturers identified for pumps and valves.

Pumps

Japan—Ebara, Teikoku, Nikkiso, Sanwa, Seikow Chemical, Iwaki, Kira, N.G.K.; **Israel**—Meltzer and Sons Ltd., Hameitz Pump MFG. Ltd.; **South Korea**—Korea Chemical Engineering Co., Ltd.

Valves

France—Gachot S.A.; **Israel**—Ham-Let Metal Products, Kim Production Ltd., EZM-MP Lachis Zafor; **South Korea**—Foxboro Korea, Ltd.

Item 5. Filling equipment enclosed in a glove box or similar environmental barrier, or incorporating a nickel-lined or Hastelloy nozzle.

Filling equipment, as described in this item, is available from manufacturers within AG and the non-AG countries of China, Taiwan, and Russia and the other newly independent states. The manufacture of Hastelloy nozzles is probably limited to Germany and Italy, although nickel-lined nozzles are available and in abundant supply on a worldwide basis. The following are known manufacturers of Hastelloy nozzles:

Germany—Sprint Metal Edelstahlziehereien, Lechler, HP + HP, and Chemie-Stellglieder; **Italy**—Cucchi Pompe and PNRI.

Item 6. Incinerators specially designed to incinerate (a) any chemical weapons agent or listed precursor; or (b) organophosphorus compounds.

Incinerators described in this item are available from AG and non-AG countries. Six countries with 13 manufacturers of this equipment are identified below, although Russia may also possess the capability to manufacture such incinerators.

Australia—Dorr-Oliver; **Finland**—Alsthom, Otokupo, and Tampella; **Germany**—Deutsche Babcock, Von Roll, Dorr-Oliver, and Lurgi; **Japan**—IHI; **Sweden**—Asea Brown Boveri (ABB), Gotaverken, and Niro; **Switzerland**—Thyssen.

Item 7. Toxic gas monitoring systems designed to detect phosphorus, sulfur, or fluorine compounds, or designed to detect any CW agent, which are (a) designed for continuous operation, *and* (b) capable of detecting such chemicals at a concentration less than 0.1 milligram per cubic meter of air.

Toxic gas monitoring systems, as described in this item, are available from the United Kingdom and Russia and the independent republics of the former Soviet Union. The United Kingdom is considered a world leader in the manufacture of detection systems for hazardous gases. The former USSR reportedly had developed a semiautomatic gas analyzer capable of detecting toxic gas concentrations at a level of 0.05 milligram per cubic meter of air. The manufacturers for this type of equipment are:

United Kingdom—SKC, Bruel & Kjaer, Neotronics, and Crowcon Instruments Ltd.; **Russia and the other newly independent states**—Odessa State University.

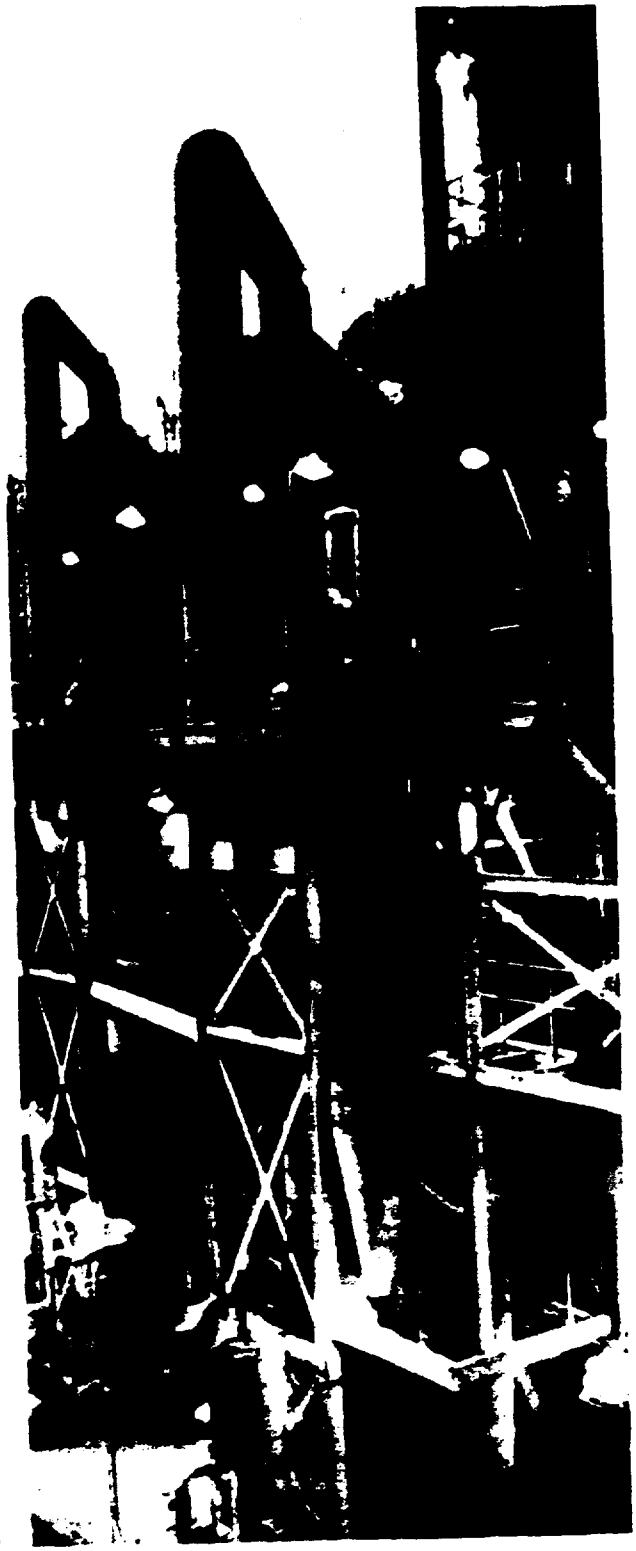
Item 8. Monitoring systems for detection of chemical compounds having anticholinesterase activity.

The availability of monitoring systems capable of detecting anticholinesterase activity is widespread, with developments in Sweden, Finland, Russia and the other newly independent states, and the former Yugoslavia. A 1989 study indicated that the newly independent states' armed forces employed the PKHR-MV analyzer during field training exercises. Manufacturers of this item are:

Former Yugoslavia—VTI facility; **Sweden**—FFC Ordnance; **Finland**—Instrumentation Oy.

Table 4 (continued)

Dryer



Evaporator

Biological Warfare: A Tutorial

Introduction

Biological warfare (BW) is the use of pathogens or toxins for military purposes. BW agents are inherently more toxic than CW nerve agents on a weight-for-weight basis and can potentially provide broader coverage per pound of payload than CW agents. Moreover, they are potentially more effective because most are naturally occurring pathogens—such as bacteria and viruses—which are self-replicating and have specific physiologically targeted effects, whereas nerve agents are manufactured chemicals that disrupt physiological pathways in a general way.

To a country considering a BW program, one advantage of biological weapons over chemical or nuclear weapons is that there are no reliable BW detection devices currently available nor are there any recognizable signals to the human senses. The delay in onset of symptoms could make it difficult to identify the time and place of the attack. Moreover, a BW attack might be readily attributable to a natural outbreak, providing the attacking country with grounds for plausible denial. In addition, biological weapons can be targeted not only against personnel, but also against crops, domestic livestock, and specific kinds of materiel.

Despite their potentially more devastating effects, biological agents have not been used on any significant scale, possibly for a number of reasons. Perhaps for some countries the principal deterrent to the actual use of BW is uncertainty about ultimate consequences. Biological weapons rarely produce instant casualties, and their effects can be uncertain. The risk, for example, of accidentally exposing friendly forces or civilian populations to BW can be dependent on changing meteorological conditions. International outrage—muted in the Iraqi CW attacks on Iranians and Kurds—could be much more severe if BW weapons, with their devastating effectiveness, result in massive casualties.

Virtually all the equipment, technology, and materials needed for biological agent production are dual use. Therefore, very little distinguishes a vaccine plant from a BW production facility. The technical skills required to start and run a program are commensurate with basic training in microbiology, and additional knowledge can easily be gained through training courses available from equipment suppliers or scientific meetings. Because of the dual-use nature of BW research and equipment, any BW program could be easily disguised as a legitimate enterprise. For example, known BW threat agents include the organisms that cause anthrax, botulism, tularemia, plague, and Q-fever; because these organisms represent a variety of clinical pathogens, extensive legitimate research is continually under way to eradicate or control them. Medical research or vaccine development, for example, requires production of such organisms on scales varying from laboratory to pilot and industrial levels.

BW Agents

Agents that have been widely recognized as having military utility include pathogens—such as bacteria, viruses, and fungi—as well as toxins. For BW purposes, these agents are incorporated into a munition or some type of dissemination system. The material delivered in the weapon is customarily defined as the BW agent.

Pathogens, defined as organisms that cause disease in man, may be grown and exploited for military purposes, as is the case for the bacterial agents that produce anthrax, plague, tularemia, and Q-fever. Other known BW threat agents include viruses—submicroscopic infective agents composed of DNA or RNA that require living cells to replicate. As BW agents, these organisms can produce a wide range of results, with varying degrees of toxicity and time of onset. The route of entry—percutaneous, ingestion, inhalation, parenteral—impacts dramatically on the effective dosage of both BW and CW agents. (For a listing of organisms that could potentially be exploited for BW applications, please see tables 5 through 8.)

Alternatively, organisms can be grown to produce toxins that are exploited in weapons, as, for example, *Clostridium botulinum*, a toxin-producing organism that is the causative agent of botulism. Toxins are poisonous compounds produced by living organisms. They are usually proteins that act upon specific receptors in the body. Most are relatively unstable to heat and other traumatic and environmental factors, although some can be separated into smaller fragments that are more stable while retaining toxicity. Toxins can be either lethal or highly incapacitating, with some having potentially greater toxicity than well-known CW agents. Toxins are produced by a variety of organisms, including microbes, snakes, insects, spiders, sea creatures, and plants.

One example of a plant toxin is ricin, which is derived from the castor bean. The use of this toxin against two Bulgarian defectors in 1978 in an "umbrella gun" underscores another application of BW agents: clandestine or terrorist use. Other examples of toxins having potential application as BW threat agents include tricothecene mycotoxins—derived from fungi—and algal toxins. Algal toxins are suited for BW purposes because of their high toxicity, the lack of vaccines and medical treatment, and the lack of detection systems deployed against them. For example, saxitoxin, produced by marine algae, acts on the nerve cells and ultimately causes respiratory arrest.

A theoretical possibility that should not be discounted for BW threat purposes is exploitation of bioregulators—organic chemicals that regulate cell processes—and physiologically active compounds such as catalysts and enzymes. Bioregulators are natural substances produced in very small quantities that are essential for normal physiological functioning of the body. They control cell and body physiological functions and regulate a broad range of functions, such as bronchoconstriction, vasodilation, muscle contraction, blood pressure, heart rate, temperature, and immune responses. These substances can be harmful, however, in large concentrations or if modifications to them bring about changes in the nature and duration of their action. Exploited in such a way for military purposes, they could potentially cause such effects as rapid unconsciousness, heart failure, paralysis, hypotension or hypertension, or psychological disturbances.

Through advanced biotechnical techniques, toxins, bioregulators, and infectious agents are subject to enhancement to increase their utility as BW agents. For example, potential types of genetically engineered disease-causing agents might include antibiotic-resistant bacteria; benign microorganisms genetically altered to produce toxins, venoms, or bioregulators; immunologically altered viruses resistant to standard vaccines and not identifiable by classical serological means; bacteria genetically altered to have advanced aerosol and environmental durability.

Production Processes and Equipment

No specialized facilities are required for the production of BW agents, since their production involves dual-use equipment and technologies such as those associated with, for example, a legitimate vaccine or pharmaceutical plant. For biological products, there are three general levels of production—***laboratory scale, pilot scale,*** and ***industrial scale.*** There are no clear demarkations of the vessel sizes for these scales, but they are

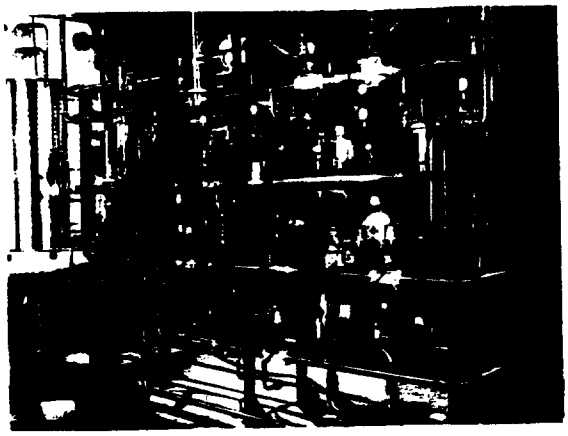


Figure 4. Research-size fermenter

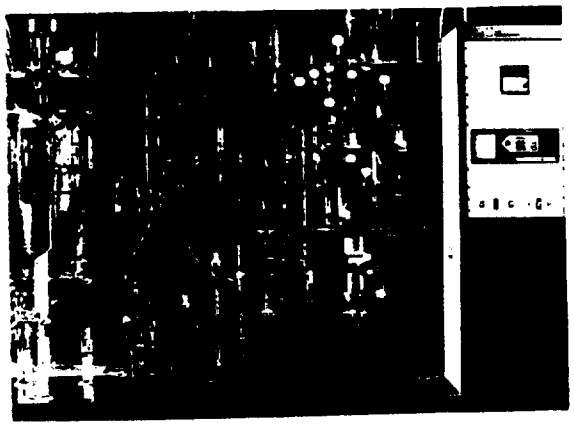


Figure 5. Pilot-scale fermenter

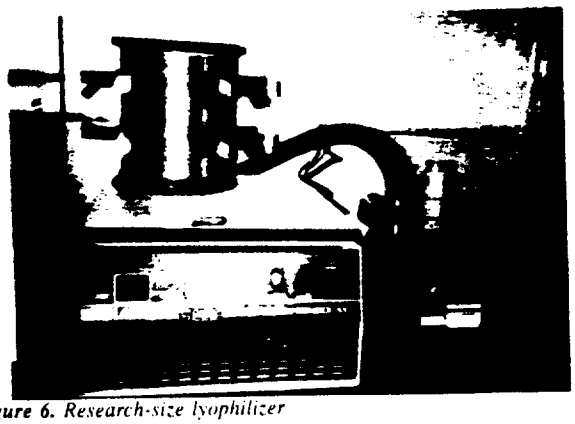


Figure 6. Research-size lyophilizer

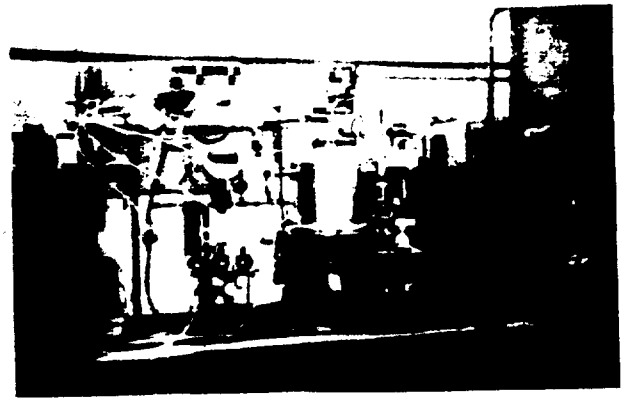


Figure 7. Continuous-flow centrifuge

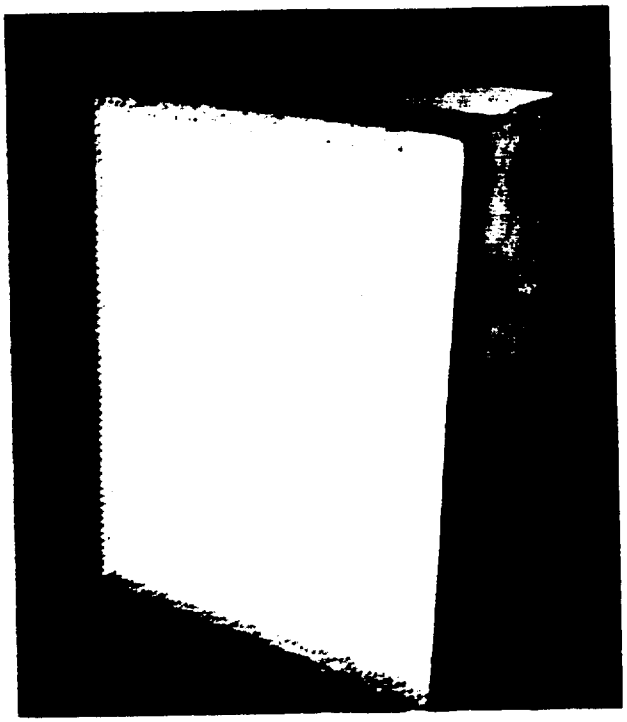


Figure 8. HEPA filter

Figure 9. "Space suits" for use in BL-4 suite

generally listed as less than 50 liters, 50 to 500 liters, and over 500 liters, respectively.

The particular scale of choice depends on the use of the end product. In commercial endeavors such as recombinant insulin production, pilot scale adequately produces enough material, while the production of antibiotics requires much larger industrial-scale volumes. For military applications, pilot scale operations could produce strategically significant quantities of agents, but even laboratory scale operations could, in time, produce enough material for military needs. Genetic engineering offers a great potential for more efficient production of BW agents—especially for those toxin agents that naturally occur in very small quantities. For example, the insertion of DNA that codes for a toxin into a ubiquitous, nonpathogenic organism allows production of significant quantities of that toxin in pilot-scale equipment.

Laboratory scale production is usually limited to research or "bench top" work. It is difficult to distinguish between legitimate commercial and offensive BW research activities because the laboratory equipment is generally the same for both or can be rapidly switched. All of the equipment used to research, develop, and produce BW agents is essential for safe and efficient handling of deadly organisms in legitimate biological research. Thus, standard biological laboratory equipment, such as fermenters, large-scale lyophilizers or freeze dryers, class II or III safety hoods, High-Efficiency Particulate Air (HEPA) filters, and centrifuges, could easily be subverted to a weapons program. International attempts are under way to control the sale of this equipment to proliferating countries, although the dual-use nature of the equipment is an inherent problem in identifying BW-related exports.

For research on highly pathogenic organisms, high-containment or maximum-containment facilities and equipment are generally utilized. The designations P-1/BL-1 through P-4/BL-4 refer to (P)rotection or (B)iocontainment (L)evel, with level 4 being the highest level of protection or containment. Basically, these level designations represent the number of physical barriers that prevent an organism from escaping to the outside from the laboratory work space. By international agreement, P-4/BL-4 is required for work on dangerous agents that pose a high risk of life-threatening diseases. High-containment laboratories (P-4/BL-4) are costly and difficult to maintain; there are only a handful of them around the world, with the majority conducting legitimate research on highly contagious diseases. It should be noted, however, that it is not necessary to have a high-containment facility for work on BW agents. For example, research of botulinum toxin and anthrax requires only a recommended P-2/BL-2 level of containment. If safety is not a concern to a country, most organisms can be researched at the lowest containment level available.

Industrial operations require both pilot- and industrial-scale equipment in order to allow the scaleup of research efforts. In general the types of equipment are very similar to those used in laboratories, except with increased capacities. Industrial-scale equipment usually has capacities of tens of thousands of liters but may be up to several hundred thousand liters. The limits are usually set by the support apparatus and the availability of raw materials, such as media, and spare parts, such as O-rings and gaskets.

There is no equipment unique to BW agent production, although the Australia Group has defined equipment parameters that would be of particular utility for BW purposes (see table 9). In the typical biological production process, an organism is grown in a fermenter in a type of media favorable to the organism's growth. While some organisms require very specific nutrients, most can be grown in generic media. Where whole cellular organisms are the desired end product, the cells are subsequently separated from the media in a centrifugal separator and converted to an appropriate form for storage. For botulinum toxin, however, the end product is the toxin that is normally secreted into the media; in this case the cells are separated from the extracellular fluid in a centrifuge and eliminated; the liquids containing the toxin are then purified. Other organisms secrete toxins within the

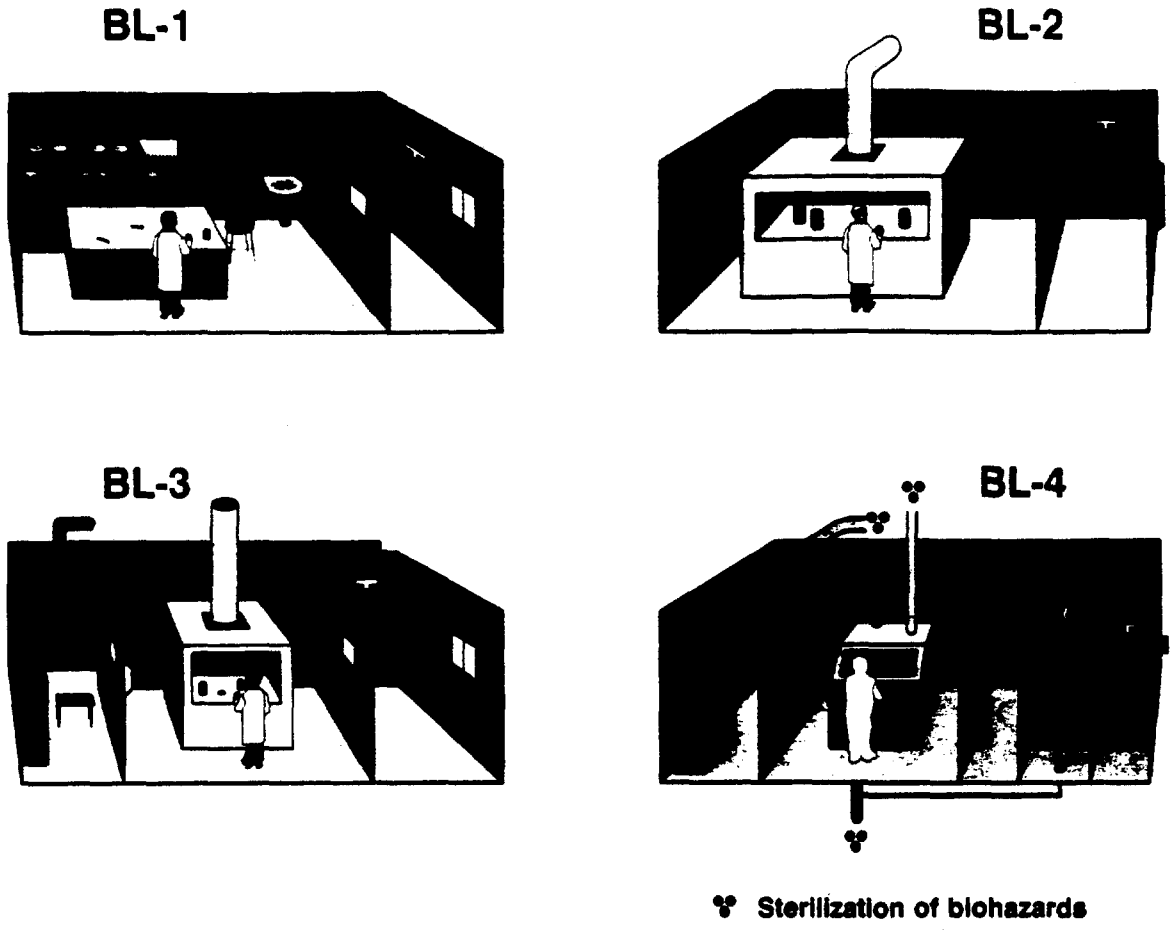


Figure 10. Biocontainment levels

cells; for isolation of these endotoxins, some form of cell wall disruption is necessary before the end product can be isolated.

The type of fermentation process depends upon the type of end product desired. The most widely used approaches include discontinuous ("batch"), anaerobic ("feed batch"), and continuous fermentation. There is extensive overlap of the volumes among these different processes.

Only recently has the technology existed to produce militarily significant quantities of BW agents. Now, virtually any known disease-causing agent can be manufactured in the laboratory, and many can be produced on an industrial scale. With genetic engineering, new possibilities have emerged, which could allow for the design of new pathogens, more virulent strains of organisms, or organisms with characteristics tailored to specific military requirements. With biotechnology and genetic engineering advances since the 1970s, it is now possible theoretically to mass-produce lethal natural products previously available only in small, militarily insignificant quantities. With recombinant DNA technology, for example, it is possible to produce new organisms, exploit variations on organisms, or induce organisms to respond in new ways, such as producing synthetic bioregulators or chemical toxins.

The Variety and Specifics of Fermentation Processes

In the discontinuous or "batch" process a single batch of nutrients is added to the fermenter. The microorganisms are then inoculated into the nutrient substrate in a process known as charging or seeding. The microorganisms are allowed to grow until the substrate has been exhausted, typically requiring as little as two days. The fermenter volume is commonly larger than that of the other processes in order to more economically exploit the nutrients. Anaerobic or "feed batch" fermentation is carried out in a batch mode in the absence of oxygen. Fresh nutrient is added periodically during production to increase product yields. Usually the product is harvested intermittently. Clostridium botulinum, *source of botulinum toxin, and* Bacillus anthracis, *positive causative organism of anthrax, are organisms grown under anaerobic fermentation conditions.*

In continuous fermentation, cells typically are kept in a state of rapid growth as the secreted end products are produced. Additional nutrients are fed into the fermenter at the same rate as the end products are removed so that conditions remain nearly constant. This process increases the overall yield because end product is produced throughout the fermentation process. A significant concern, however, in long-term continuous fermentation is possible contamination by undesirable organisms. This risk is minimized by carefully monitoring the output and terminating the process if contamination is detected.

There are numerous types of fermentation vessels available. A standard, general purpose fermenter consists of a cylindrical metal vessel (usually stainless steel) with a 2:1 height-to-diameter ratio and either a cone-shaped or a sloping bottom to facilitate emptying. The fermenter also has a number of ports for adding nutrients, removing content samples, and inserting control probes. Larger fermenters have integrated steam systems for cleaning and sterilization. The tank may be fitted with openings for venting or collecting waste gases. Most are equipped for agitation by baffle plates fitted inside the fermentation tank and an intermeshing motor-driven impeller. The general types of fermenters include stirred tanks, airlift, chemostatic, cell, immobilized cell (or enzyme), hollow-fiber, and heavy-ton.

The stirred tank and heavy-ton vessels have all the features described above. The heavy-ton, however, are much larger and are commonly used commercially for Single Cell Protein (SCP) production—a microbial-based product used for animal feeds. These systems are well suited for most BW agent production. Airlift systems use bubbling air from the bottom of the vessel to stir the broth instead of an agitator. These systems would be well suited for fragile organisms but could not be used in anaerobic fermentation. Chemostatic fermenters are designed to facilitate the continuous fermentation process. The cell, immobilized cell, and hollow-fiber fermenters are designed to provide a small growth surface for the cells by physically separating the cells from the growth media while allowing diffusion of nutrients and end products through membranes. These three allow greater and more efficient yields and are more commonly used with animal cell systems that have greater growth regulation requirements than bacterial cells.

Procurement Issues

International attempts to stem BW proliferation have focused either on suppliers (as the Australia Group is doing) or on self-disclosures and declarations (under the Biological and Toxin Weapons Convention of 1972). However, supplier responsibilities can be clouded by the dual-use nature of the equipment, and BW developers could claim legitimate defensive research activities or attribute production accidents to naturally occurring epidemics.

Both the materials and the technical skills needed to start up a modest offensive BW program are easily attainable and relatively cheap. In general, most organisms needed for a potential offensive BW program are readily available through commercial repositories that isolate, preserve, and dis-

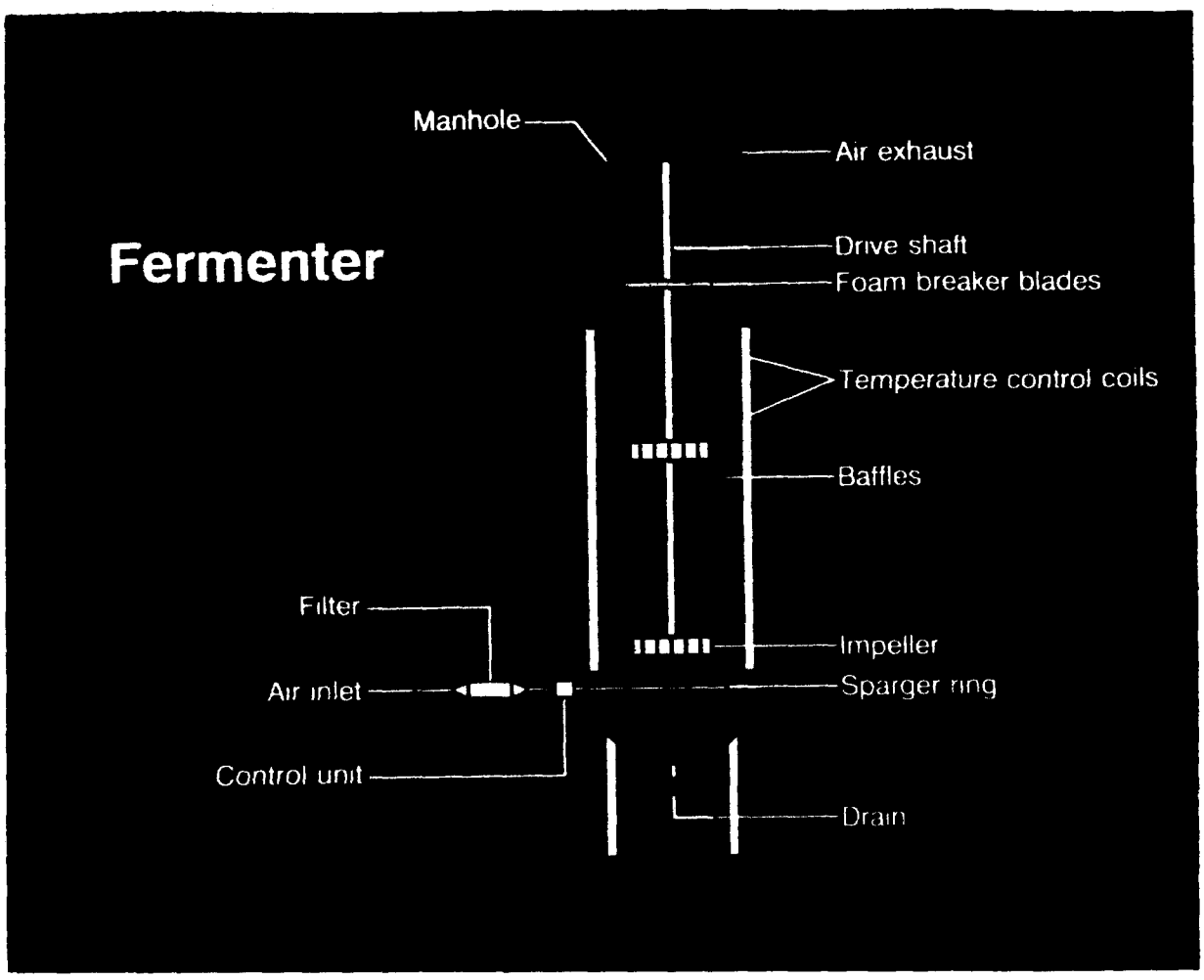


Figure 11. Fermenter

tribute cultures. Such repositories can supply thousands of differing bacterial cultures, frozen or freeze-dried, including classical BW agents such as anthrax and *Clostridium botulinum*. An anthrax culture costs approximately $45 from a US repository. The current requirement is a signed form accepting responsibility for the receipt and attesting to the existence of adequate facilities and practices to work with potentially highly pathogenic materials. Until very recently, no other verifications were necessary to receive such pathogens. The United States initiated the requirement for end-user certificates on certain pathogenic organisms, but even this measure can be circumvented by otherwise legitimate companies acting on the behalf of BW programs. Starting cultures could also be traded, stolen, or obtained gratis from other research, clinical, or veterinary laboratories or scientists. And finally, any organism may be isolated from the environment.

The equipment and materials needed to produce BW agents, likewise, are easily obtained or can be adapted from readily available items. Virtually any

type flask or useful container can be sterilized in an everyday pressure cooker and used to grow the organism. A 20-liter fermenter combined with a filling port can be obtained from a home brewing supplier for under $50. These suppliers can also be a source of larger capacity fermenters. Although there are specialized complex media for some of the agents used in BW programs, most agents can be grown in readily available materials. This material may be as simple as augmented animal feeds or easily available milk products. (See table 10 for a list of bioprocessing equipment suppliers.)

Finally, it should be noted that advances in biotechnology have eliminated the need for a stockpile of BW agents. Proliferating nations only need a starter culture of agent; they can then wait until they wish to use biological weapons to produce the quantities required. In contrast to a CW program, for example, there is no need in BW efforts for a continuing supply of sizable quantities of precursor chemicals and raw materials.

The following attached tables are provided for reference purposes, as an aid in determining the potential applicability of materials and equipment to biological agent production. A list of producers of equipment with such potential applications is included as table 10.

Table 5
Biological Warfare Agents: Examples

Disease	Causative Agent	Incubation time (*days*)	Fatalities (*percent*)
Anthrax	*Bacillus anthracis*	1-5	80
Plague	*Yersinia Pestis*	1-3	90
Tularemia	*Francisella tularensis*	1-10	5-20
Cholera	*Vibrio cholerae*	2-5	25-50
Venezuelan equine encephalitis	VEE virus	2-5	< 1
Q fever	*Coxiella burnetti*	12-21	< 1
Botulism	*Clostridium botulinum* toxin	3	30
Staphylococcal enterotoxemia (food poisoning)	*Staphylococcus enterotoxin* type B	1-6	< 1
Multiple organ toxicity	Trichothecene mycotoxin	Dose dependent	

Table 6
Core List of Organisms Having Potential BW Applications

Viruses
Chikungunya virus
Congo-Crimean haemorrhagic fever virus
Dengue fever virus
Eastern equine encephalitis virus
Ebola virus
Hantaan virus
Junin virus
Lassa fever virus
Lymphocytic choriomeningitis virus
Machupo virus
Marburg virus
Monkey pox virus
Rift Valley fever virus
Tick-borne encephalitis virus (Russian Spring-Summer encephalitis virus)
Variola virus
Venequelan equine encephalitis virus
White pox
Yellow fever virus
Japanese encephalitis virus

Rickettsiae
Coxiella burnetii
Rickettsia quintana
Rickettsia prowasecki
Rickettsia rickettsii

Bacteria
Bacillus anthracis
Brucella abortus
Brucella melitensis
Brucella suis
Chlamydia psittaci
Clostridium botulinum
Francisella tularensis
Pseudomonas mallei
Pseudomonas pseudomallei
Salmonella typhi
Shigella dysenteriae
Vibrio cholerae
Yersinia Pestis

Genetically Modified Microorganisms Which
(a) Contain nucleic acid sequences associated with pathogenicity and are derived from organisms in the core list.
(b) Contain nucleic acid sequences coding for any of the toxins in the core list.

Toxins
Botulinum toxins
Clostridium perfringens toxins
Conotoxin
Ricin
Saxitoxin
Shiga toxin
Staphylococcus aureus toxins
Tetrodotoxin
Verotoxin
Microcystin (Cyanginosin)

Table 7
Animal Pathogens With Potential BW Applications

African swine fever virus
Avian influenza virus (only those of high pathogenicity)
Bluetongue virus
Foot and mouth disease virus
Goat pox virus
Herpes virus (Aujeszky's disease)
Hog cholera virus
Lyssa virus
Newcastle disease virus
Peste des petits ruminants virus
Porcine enterovirus type-9
Rinderpest virus
Sheep pox virus
Teschen disease virus
Vesicular stomatitis virus

Bacteria
Mycoplasma mycoides

Genetically Modified Microorganisms
Genetically modified microorganisms or genetic elements that contain nucleic acid sequences associated with pathogenicity and are derived from organisms in the core list.

Table 8
Warning List

Viruses
Kyasanur Forest virus
Louping ill virus
Murray Valley encephalitis virus
Omsk haemorrhagic fever virus
Oropouche virus
Powassan virus
Rocio virus
St. Louis encephalitis virus

Bacteria
Clostridium perfringens
Clostridium tetani
Enterohaemorrhagic Escherichia coli serotype 0157 and other verotoxin producing serotypes
Legionella pneumophila
Yersinia pseudotuberculosis

Genetically Modified Microorganisms Which
Genetically modified microorganisms or genetic elements that contain nucleic acid sequences associated with pathogenicity and are derived from organisms in the warning list.

Genetically modified microorganisms or genetic elements that contain nucleic acid sequences coding for any of the toxins in the warning list.

Toxins
Abrin
Cholera toxin
Tetanus toxin
Trichothecene mycotoxins

Table 9
General Guidelines for Identifying Dual-Use Biological Equipment and Related Technology

Class III animal housing

Double-walled aerosol chamber

1. Complete Containment Facilities at P3/BL3, P4/BL4 Containment Level

Complete containment facilities that meet the criteria for P3 or P4 (BL3, BL4, L3, L4) containment (as specified in the WHO Laboratory Biosafety Manual).

2. Fermenters

(a) Capacity equal to or greater than (300) liters (L).

(b) Made of polished stainless steel, borosilicate glass, polished aluminum (or plastic/other non-corrodible material).

Table 9 (continued)

(c) Double or multiple sealing joints within the steam containment area.

(d) Capable of in situ sterilization in a closed state.

3. Centrifugal Separators

(a) Flow rate greater than 100 liters per hour.

(b) Components of polished stainless steel or titanium.

(c) Double or multiple sealing joints within the steam containment area.

(d) Capable of in situ steam sterilization in a closed state.

4. Freeze Drying Equipment

Steam sterilizable freeze drying equipment with a condensor capacity greater than 50 kgs of ice in 24 hours and less than 1,000 kgs of ice in 24 hours.

5. Cross-Flow Filtration Equipment

Cross-flow filtration equipment designed for continuous separation of pathogenic microorganisms, viruses, toxins, and cell cultures without the propagation of aerosols, having all the following characteristics:

(a) Equal to or greater than 5 square meters.

(b) Capable of in situ sterilization.

6. Equipment That Incorporates or Is Contained in P3 or P4 Containment Housing, Specifically

(a) Independently ventilated protective full or half suits.

(b) Class III safety cabinets or isolators with similar performance standards.

7. Aerosol Inhalation Chambers

Chambers designed for aerosol challenge testing with pathogenic microorganisms, viruses, or toxins and having a capacity of 1 cubic meter or greater.

Other equipment:

1. Equipment for the microencapsulation of live microorganisms and toxins in the range of 1 to 10 meters particle size, specifically:

(a) Interfacial polycondensors.

(b) Phase separators.

2. Fermenters of less than 300-liter capacity with special emphasis on aggregate orders or designs for use in combined systems.

3. Conventional or turbulent air-flow clean-air rooms and self-contained fan-HEPA filter units that may be used for P3 or P4 (BL3, BL4, L3, L4) containment facilities.

Table 10
Availability Review of Key Dual-Use Bioprocessing Equipment

1. Worldwide manufacturers of fermenters

Confirmed Sources (manufacturers capable of producing fermenters of 100 liters or greater):

Australia Group	Manufacturer
Australia	B Braun Australia Pty. Ltd.
	Sulzer Australia Pty. Ltd.
Austria	Andritz Maschinenfabrik AG
Belgium	Sulzer Belgium SA/NV
Canada	Pegasus Industrial Specialties, Ltd.
	Sulzer Canada, Inc.
	WHE Process Systems, Ltd.
Denmark	Alfa-Laval AS
France	Chemap (made in Switzerland)
	Inceltech
	LSL Biolafitte SA
	SGi Setric Genie Industriel
Germany	Alfa-Laval Industrie GmbH
	B Braun Diessel Biotech GmbH
	Chemap GmbH (made in Switzerland)
	New Brunswick Scientific GmbH (made in US)
	Sulzer-Escher Wyss GmbH
Hungary	Vegyepszer
Italy	Alfa-Laval SpA
	B Braun Milano SpA (made in Germany)
Japan	B Braun Biotech Co., Ltd. (made in Germany and Malaysia)
	Marubishi Bioengineering Co., Ltd.
	Mitsuwa Rikagaku Kogyo Co., Ltd.
Netherlands	Applikon Dependable Instruments BV
	Sulzer Nederland BV
Sweden	Chemoferm AB
	Electrolux Fermentation
Switzerland	Bioengineering AG
	Chemap AG
	LSL Secfroid SA
	MBR Bio Reactor AG
United Kingdom	B Braun Medical, Ltd.
	Bioengineering UK, Ltd.
	Centech, Ltd.
	FT Applikon, Ltd.
United Kingdom (continued)	LH Fermentation, Ltd.
	Life Sciences Laboratories, Ltd.
	MBR Bio Reactor (UK), Ltd.
	Sulzer (UK), Ltd.

Non-Australia Group	Manufacturer
Brazil	Sulzer do Brasil SA Industria e Comercio
Bulgaria	Scientific Research Lab for Instrument Making and the Automation of Biological Experiments
Czech Republic and Slovakia	Kralovopolska Stroyirna
Russia and the other newly independent republics	All-Union Scientific Research Design Institute of Applied Biochemistry
	Institute of the Biochemistry and Physiology of Microorganisms
	Irkutsk Scientific Research Institute of Chemical Machines
	NPO Biopribor
	NPO Biotekhnika
	Special Design Bureau for Biological Instruments
South Korea	Korean Fermentor Co.

Unconfirmed Sources:

Australia Group	Manufacturer
Australia	Bulkon Australia Pty. Ltd.
	Cawthron Institute
Austria	Arge Biotechnologie
	Raiffeisen-Bioforschung
	Vogelbusch
Belgium	Belgolab SA
	Biotim N.V.
	Elscolab NV
	Holurieka NV
	Microgon, Inc.
Canada	Mueller Canada, Inc.
	The SNC Group
	St. Lawrence Reactors, Ltd.
	Techneurop, Inc.
	Wardrop Engineering, Inc.

Table 10 (continued)

Finland	G. W. Berg & Co., AB
	Rintekno OY
France	Bertin & Cie
	Bignier Schmid Laurent
	Biolog
	BSL Industries SA
	CCM
	Cellier SA
	Flobio
	Goavec
	Interscience
	Lequeux
	Pharmacia LKB Instruments SA
	Sonertec
Germany	Aluminiumgiesserei Neukoelin Oskar
	Waltersdorf GmbH
	Atlantik Geraetebau GmbH
	Bioinvest Engineering
	Buero Biotechnik
	Deutsche Metrohm GmbH & Co.
	Diessel GmbH & Co.
	Fr Kammerer GmbH
	Friedrich & Hofmann
	Heinrich Frings GmbH
	Holag Technologie AG
	Holurieka GmbH
	IBL GmbH
	IMA GmbH
	Kalger GmbH
	KC Biological
	Kraftanlangen Heidelberg AG
	Lang Labortechnik
	Membran-Tecknik-Hamburg
	PRG Praaezisions-Ruehrer GmbH
	Schuett Labortechnik GmbH
	Siemens AG
	Then Maschinen un Apparatebau GmbH
	VEB Chemieanlagenbaukombinat
Hungary	Mafki Ungar. Erdoel-und Erdgas Forschunginstitut
	Magyar Tudomanyos Akademia
Ireland	P J Brennan & Co., Ltd.
Italy	A Biotec
	Olsa SpA
	Oxytek SAS
	Vismara Associates SpA
Japan	Fuji Electric Co.
	Hirayama Manufacturing Corp.
	Hitachi, Ltd.
	Idemitsu Kosan Co.
	Kawasaki Heavy Industries
	Mitsubishi Heavy Industries
	Nippon Kokaan K.K.
	Nisshin Oil Mills, Ltd.
	Yakult Honsha Co., Ltd.
Netherlands	Amsterdam Valve & Fitting BV
	APV Nederland BV
	Bert Versteeg-Veetech BV
	Contact Flow
	Dalton BV
	Holurieka Holding BV
	Lameris Laboratorium
	Marius Instruments
	Netherlands Institute for Dairy Research
	Pharmacia Nederland BV
	Rhone Poulenc Nederland BV
	Salm & Kipp
	Vogelaar Electronics
Spain	CETS Institut Quimico de Sarria
	Knoik Instruments SA
Sweden	Biolink
	Ninolab AB
Switzerland	Amicon Division
	Arbeitsgemeinschaft Bioenergie
	Lonza, Ltd.
	Rosenmund AG
United Kingdom	Alcon Biotechnology, Ltd.
	Alfa-Laval Engineering, Ltd.
	Anglicon Instruments, Ltd.
	APV Baker
	APV Barnetta Rolfe, Ltd.
	B & P Biotechnology, Ltd.
	BS Flocor, Ltd.
	Catalytic International, Inc.

Table 10 (continued)

United Kingdom (continued)	Charles River UK, Ltd.
	Chemquip, Ltd.
	Dulas Engineering, Ltd.
	ECC International, Ltd.
	Endotronics
	Fairey Engineering, Ltd.
	GB Biotechnology, Ltd.
	Henfrey Engineering
	Hickey & Co., Ltd.
	Imperial Biotechnology, Ltd.
	Life Technologies, Inc.
	Lummus Crest, Ltd.
	MacLeod & Miller (Engineers), Ltd.
	Mass Transfer International
	Matthew Hall Engineering, Ltd.
	National Engineering Laboratory
	NEBC Developments
	Penrhos Electronics
	Pharmacia-LKB Biochrom, Ltd.
	Roth Scientific Co., Ltd.
	Schaefer Instruments, Ltd.
	SGi (UK), Ltd.
	Techmation, Ltd.
	TechnoGen Systems, Ltd.
	Titanium Fabricators, Ltd.

Non-Australia Group	**Manufacturer**
Brazil	Biobas
	Centro de Technologia Promon
	CESHMT Com & Repr, Ltd.*
	Codistil
	Coperucar
	Dedini SA
	Faculdade de Engenharia Industrial
	Setal Instalacoes Industrias SA
	TECHPAR
	Zanini SA Equipmentos
Czech Republic and Slovakia	Kovodruzhstvo
	Microbiology Institute of the Czechoslovakia Academy of Sciences
	Yednotne Zemyedyelske Druzhestvo Rude Armady
China	Beijing Institute of Chemical Metallurgy
	Dalian Institute of Chemical Physics
Russia and the other newly independent republics	All-Union Scientific Research Biotechnology Institute
	Livani Biochemical Plant
	Shebekino Biochemical Plant
South Korea	Doosan Manufacturing Co.
(Former) Yugoslavia	Livani Biochemical Plant
	Shebekino Biochemical Plant

2. Worldwide manufacturers of centrifugal separators

Probable Manufacturers of Centrifugal Separators

Australia Group	**Manufacturer**
Australia	Beckman Instruments Pty, Ltd.
Austria	Heraeus Wien
	Westfalia Separator Austria GmbH
Denmark	6V Separation AS
	Alfa-Laval Separation AS
France	Alfa-Laval SA
	Beckman
	Dupont de Nemours SA
	Jouan SA
Germany	Alfa-Laval Industrietechnik GmbH
	Heraeus-Christ Separationstechnik GmbH
	Heraeus-Sepatech GmbH
	Kontron Instruments GmbH
Italy	Alfa-Laval SpA
	Beckman Analytical SpA
	Dupont de Nemours Italiana SpA
Japan	Alfa Laval K.K.
Netherlands	Labinco BV
	Lameris Laboratorium
Norway	Heigar & Co. AS
	Nyegaard & Co. AS
Sweden	Bergman & Beving AB
Switzerland	Alfa-Laval Industriegesellschaft AG
	Dr. Bender & Dr. Hobein AG
	Heraeus AG
	LSL Secfroid SA
	Treff AG

Table 10 (continued)

United Kingdom	A. R. Horwell, Ltd.
	Alfa-Laval Engineering, Ltd.
	APV Chemical Machinery, Ltd.
	Baird & Tatlock, Ltd.
	Burkard Scientific, Ltd.
	Camlab, Ltd.
	Centrilab
	Damon/IEC, Ltd.
	Denley Instruments, Ltd.
	Dupont (UK), Ltd.
	Eltex of Sweden, Ltd.
	Hawksley & Sons, Ltd.
	Jouan, Ltd.
	MSE
	MSE Scientific Instruments
	Nycomed, Ltd.
	Nygaard (UK), Ltd.
	Sarstedt, Ltd.
	Simsons of Edinburgh, Ltd.
	V. A. Howe & Co., Ltd.
	Zeta Engineering, Ltd.

Other Worldwide Manufacturers of Centrifugal Separators

Australia Group	Manufacturer
Belgium	Sanki Engineering, Ltd.
	Sweco Europe SA
Canada	Sarstedt Canada, Inc.
Finland	Finn Metric OY
France	Guinard Centrifugation
	Kontron
	NEN France Sarl
	Rousselot Ets
Germany	AMKO Light Technology Instruments GmbH
	Andreas Hettich
	Berthold Hermle GmbH
	Carl Padberg Zentrifgenbau GmbH
	Electro-Nucleonics International, Ltd.
	Eppendorf-Netheler-Hinz GmbH
	Hettich-Zentrifugen
	Industrienlagen AG
	Wimmer GmbH
	Zirbus-Verfahrenstechnik
Italy	Hewlett Packard Italian SpA
Japan	Fuji Filter Manufacturing Co., Ltd.
	Hitachi Koki Co., Ltd.
	Mitsubishi Kakoki Kaisha, Ltd.
	Nippon Atomic Industry Group Co.
	Shinmaru Enterprises Corp.
Netherlands	Amsterdam Valve & Fitting BV
	Pijttersen BV
Portugal	Elnor
Spain	Hucoa-Erloss SA

Non-Australia Group	Manufacturer
Malaysia	Juru Rubcoil Sdn Bhd
Russia	Moscow Production Institute of the Food Industry
	All-Union Scientific Research and Experimental Design Institute of the Food Machine Building Industry
South Korea	Han Seong Machinery Manufacturing Co.
	Korea Storage Battery Co.
Taiwan	Bestway Corp.
	Chang Jung Business Company, Ltd.
	Sui Sheng Refrigeration Engineering Co.
	Yau Yuan Industrial Machinery Co.
Ukraine	Kharkov Institute of Mechanization and Electrification of Agriculture

Other Countries

Both Israel and the Republic of South Africa possess the technological know-how, industrial capability, and supporting infrastructure to produce the most advanced centrifuges. India, Brazil, and Pakistan are also potential producers.

3. Worldwide manufacturers of freeze dryers

Confirmed Sources (manufacturers capable of producing units over 1,000 liters per batch capacity):

AG Countries	Manufacturer
Finland	Finn-Acqua Corp. (owned by AMSCO)
France	Cellier
	CIRP/Serail
	Usifroid S. A.
Germany	Leybold-Heraeus GmbH (owned by AMSCO)
United Kingdom	Edwards High Vacuum Intl. (British Oxygen) (owned by AMSCO)

Table 10 (continued)

Non-Australia Group

None identified

Unconfirmed Sources

AG Countries	Manufacturer
Austria	Labin
	Reichert-Jung
Denmark	Atlas (manufactures automated tray loading freeze dryers for the food industry)
France	Biolafitte
	Froilabo Biomedical
	Group S. G. D.
	Heraeus
	Hibbon Intl.
	Rua Instruments
Germany	Alb. Klein GmbH
	Martin Christ GmbH & Co., KG.
	Polimex
Italy	Edvards Alto Vuoto
Japan	Osaka Gas
Netherlands	Grenco BV
Portugal	Cassel Industrias
Spain	Telstar S. A.
Switzerland	Salvis
United Kingdom	Tech

Non-Australia Group	Manufacturer
India	Aircons Pvt., Ltd.
	Coil Company, Ltd.
	Ice-King Refrigeration Engineering
	Ice & Diesel Engineering Works
	Super Refrigeration, Ltd.
Israel	Polipach, Ltd.
Malaysia	Juru Rubcoil Sdn Bhd
Poland	Polimex-Cekop
China	Changchun Pneumatic Components
Singapore	Associated Instrument Mfg. (S), Ltd.
	O.S.L. Sinko
Taiwan	Bestway Corp.
	Chang Jung Business Co., Ltd..
	Fu Sheng Ind Co., Ltd.
	Sui Sheng Refrigeration Eng. Co.
	Yau Yuan Ind Machinery Co., Ltd.
Russia and the other newly independent republics	Institute of the Problems of Cryobiology and Cryomedicine.

4. Aerosol generators specially designed to disseminate live microorganisms or spores

These items may not be commercially available, although aerosol generators commonly used in the agriculture industry to disseminate biological and chemical pesticides may be capable of disseminating BW agents.

5. Equipment for the microencapsulation of live microorganisms

Equipment used for microencapsulation of live microorganisms is available worldwide. Although the process known as coacervation was patented over 30 years ago, certain specialized equipment and technical know-how appear to be the most critical aspects of this item.

6. Biohazard containment equipment, as follows: (a) complete BL-3 or BL-4 level laboratory facilities, (b) equipment or components intended for the construction of such facilities

Equipment as described in this item is available within and outside the AG countries, including sources in China and Taiwan. Foreign manufacturers of this equipment include:

7. Detection or assay systems for biological agents or toxins, capable of detecting concentrations less than one part per million in air

Based on published information, the German multinational firm Draeger Akritngesellschaft appears to be the only manufacturer of this item. Draeger is considered a world leader in the production of sensitive devices for monitoring toxic substances. In addition to its Luebeck-based firm, Draeger has production and distribution facilities located throughout the world, including distribution facilities in Toronto, Canada, and Pittsburgh, Pennsylvania.

8. Complex media for the growth of microorganisms in Class 3 or Class 4, in quantities greater than 100 kilograms, specially brain/heart infusion media

The material described in this item typically consists of a base of soybean milk or dry milk casein powder infused with a broth of the organs from animals. Russia and the other newly independent republics and Cuba possess the technology to commercially produce such media, which is also available from Germany and the United Kingdom.

A Glossary of Terms

Acetylcholinesterase
An enzyme that hydrolyzes the neurotransmitter acetylcholine. The action of this enzyme is inhibited by nerve agents.

Aerosol
A suspension of small, finely divided particles, either liquid or solid, in a gas; for example, fog or smoke.

Antibody
A protein made by vertebrates as the immune response to a foreign macromolecule, or antigen.

Atropine
A compound used as an antidote for nerve agents. It is used medically in its sulfate form to inhibit the actions of acetylcholine in the parasympathetic nervous system.

BL/P levels
There are four biosafety levels (BLs) that conform to specified conditions; these conditions consist of a combination of laboratory practices and techniques, safety equipment, and laboratory facilities appropriate for the operations performed and the hazard posed by the infectious agents. Formerly described as "physical containment (P)" levels.

Binary munition
A chemical munition divided into two sections, each containing precursor chemicals that combine and react during flight, releasing a chemical agent upon impact.

Biological warfare
The use, for military or terrorist purposes, of living organisms or material derived from them, which are intended to cause death or incapacitation in man, animals, or plants.

Bioregulators
Biochemicals that regulate physiological functions and are produced naturally in the body; in inappropriate concentrations, however, they can cause harmful effects.

Biotechnology
Applied biological science; for example, genetic engineering and biofermentation processes.

Blister agent
A chemical agent that can cause blistering of the skin and extreme irritation of the eyes and lungs; although primarily an incapacitant, it can cause death in large doses. Examples are sulfur mustard, nitrogen mustard, and lewisite.

Blood agent
A chemical agent that acts on hemoglobin in blood cells, thus preventing oxygen from reaching cells. Examples are hydrogen cyanide and cyanogen chloride.

Chemical warfare
The military use of toxic substances such that their chemical effects on exposed personnel result in incapacitation or death.

Choking agent
A chemical agent that is typically a nonpersistent, heavy gas. It irritates the eyes and throat and, when inhaled, can lead to pulmonary edema, resulting in death from lack of oxygen. Examples are chlorine and phosgene.

Culture
A population of microorganisms grown in a medium.

Cutaneous
Pertaining to the skin.

DNA
Deoxyribonucleic acid: the genetic material of all organisms and viruses (except for a small class of RNA-containing viruses) that code for structures and materials used in normal metabolism.

Electrophoresis
A technique that separates molecules based on size and/or charge.

Endogenous
Produced or originating from within.

Endotoxin
A toxin produced in an organism and liberated after disruption of the cell wall.

Enterotoxins
Toxins of bacterial origin specific for cells of the intestine.

Enzyme
A protein formed by living cells which acts as a catalyst on physiological chemical processes.

Exogenous
Produced or originating from without.

Exotoxin
A toxin excreted by a microorganism into the surrounding medium.

G-series nerve agents
Chemical agents of moderate to high toxicity developed in the 1930s that act by inhibiting a key nervous system enzyme. Examples are tabun (GA), sarin (GB), soman (GD), and GF.

Genetic engineering
The directed alteration or manipulation of genetic material.

Hemoglobin
The constituent of red blood cells that carries oxygen and gives them their color.

Infectious
Capable of producing disease in a susceptible host.

LD_{50}
The dose (LD is lethal dose) that will kill 50 percent of the exposed population.

Medium
A substance used to provide nutrients for the growth and multiplication of microorganisms.

Microorganism
Any organism of microscopic dimensions.

Monoclonal antibody
A single, pure antibody; made from hybridoma cells.

Nerve agent
A chemical agent that acts by disrupting the normal functioning of the nervous system.

Nonlethal agents
Chemical agents that can incapacitate but which, by themselves, are not intended to cause death. Examples are tear gas, vomiting agents, and psychochemicals such as BZ and LSD.

Organophosphorus compound
A compound, containing phosphorus and carbon, whose physiological effects include inhibition of cholinesterase; many pesticides and virtually all nerve agents are organophosphorus compounds.

Pathogen
Any agent capable of producing disease, although usually applied to living agents.

Percutaneous
Through the skin; when applied to chemical agents, refers to route of entry into the body.

Persistence
A measure of the duration for which a chemical agent is effective. This property is relative, however, and varies by agent, by method of dissemination, and by environmental conditions such as weather and terrain.

Precursor
A chemical that can be chemically combined with another substance to form a chemical warfare agent. Most precursors controlled through international efforts have commercial uses as well.

Psychochemical agent
An agent that incapacitates by distorting the perceptions and cognitive processes of the victim.

Pulmonary edema
The excessive accumulation of fluid in lung tissue.

Recombinant DNA (rDNA)
DNA prepared in the laboratory by splitting and splicing DNA from different species, with the resulting recombinant DNA having different properties than the original.

Restriction enzyme
An enzyme that splits DNA at a specific sequence.

Riot control agents
Substances, usually having temporary effects, that are used typically by governmental authorities for law enforcement purposes.

Toxicity
A measure of the harmful effect produced by a given substance on a living organism.

Toxins
Poisonous substances produced by living organisms.

Toxoid
A toxin biologically inactivated by chemical or physical means, usually for vaccine production purposes. Because a prerequisite for toxoid generation is toxin production, the technology involved has applicability to BW.

V-series nerve agents
A class of chemical agents developed in the 1950s that act by inhibiting a key nervous system enzyme. They are generally persistent and have a moderate to high toxicity. Examples are VE, VG, VM, VS, and VX.

Vaccine
A substance administered to induce immunity in the recipient.

Vesicant
A blistering agent.

Virulence
The capacity of a microorganism to produce disease.

Virus
A submicroscopic infectious agent that is characterized by a total dependence on living cells for reproduction and that lacks independent metabolism.

Volatility
A measure of how readily a liquid will vaporize.