

FIREPOWER IN THE LAB

**Automation in the
Fight Against
Infectious Diseases
and Bioterrorism**

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Biological Weapons: Past, Present, and Future

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Biological weapons are weapons of mass destruction (or mass casualty weapons, to be precise, because they do not damage nonliving entities) that are based on bacteria, viruses, rickettsiae, fungi, or toxins produced by living organisms. Compared to nuclear, chemical, or conventional weapons, biological weapons are unique in their diversity. Dozens of different agents can be used to make a biological weapon, and each agent will produce a markedly different effect. These differences are shaped by various properties of the particular agent, such as its contagiousness, the length of time after release that it survives in the environment, the dose required to infect a victim, and, of course, the type of disease that the agent produces. Biological weapons are relatively inexpensive and easy to produce. Although the most sophisticated and effective versions require considerable equipment and scientific expertise, primitive versions can be produced in a small area with minimal equipment by someone with limited training.

Biological weapons can be deployed in three ways: by contaminating food or water supplies; by releasing infected vectors, such as mosquitoes or fleas; or by creating an aerosol cloud to be inhaled by the victims. Because industrialized countries have adequate water purification systems, contamination of the water supply is the least effective method for disseminating a biological weapon in these countries. Contamination of food supplies would most likely be used in a terrorist attack because it is difficult to contaminate enough food to gain a military advantage. Release of infected vectors is not particularly efficient for either military or terror-

ist purposes and entails a high probability of affecting those producing the weapons or living nearby.

By far the most effective mode for applying biological weapons is an aerosol cloud. Such a cloud is made up of microscopic particles and is therefore invisible. It can be produced in several ways, most of which involve either an explosion (some type of bomb) or spraying (usually involving a special nozzle on a spray tank). The effectiveness of the cloud is determined by numerous factors, such as the amount of agent that survives the explosion or spraying and the wind and weather conditions outdoors or air flow and ventilation indoors.

The primary result of an effective aerosol cloud is simultaneous infections among all those who were exposed to a sufficiently dense portion of the cloud. If the agent is contagious, the disease will then spread. In addition, agents that can survive for a long time in the environment will eventually settle, contaminating the ground, buildings, water and food sources, and so on. In some cases these sediments can form another dangerous aerosol cloud if they are disturbed.

Many countries have produced biological weapons for military use. The United States had a biological weapons program until 1969. Japan produced and deployed biological weapons during World War II. But by far the biggest and most sophisticated biological weapons program was that of the Soviet Union. Although the Soviet Union was a party to the 1972 Biological and Toxin Weapons Convention, it developed and produced biological weapons in huge quantities through at least the early 1990s. The size and scope of this program were enormous. For example, in the late 1980s and early 1990s, over 60,000 people were employed by the agencies responsible for the research, development, and production of biological weapons. Hundreds of tons of anthrax weapon formulation were stockpiled, along with dozens of tons of smallpox and plague. The total production capacity of all of the facilities involved was many hundreds of tons of various agents annually.

The Soviet Union's biological weapons program was established in the late 1920s. Before World War II, research was conducted on a wide variety of agents. But by the beginning of the war, the Soviet Union was able to manufacture weapons using the agents for tularemia, epidemic typhus, and Q fever and was also working on techniques for producing weapons using the agents for smallpox, plague, and anthrax. Analysis of a tularemia outbreak among German troops in southern Russia in 1942 indicated that this incident was very likely the result of the USSR's use of biological weapons. There was also a suspicious outbreak of Q fever in 1943 among German troops vacationing in the Crimea.

After the war, the Soviet program continued to expand and develop. While the prewar list of weaponized agents included tularemia, epidemic

typhus, and Q fever, the postwar list was expanded to include smallpox, plague, anthrax, Venezuelan equine encephalomyelitis, glanders, brucellosis, and Marburg infection. Numerous other agents were studied for possible use as biological weapons, including Ebola, Junin virus (Argentinian hemorrhagic fever), Machupo virus (Bolivian hemorrhagic fever), yellow fever, Lassa fever, Japanese encephalitis, and Russian spring-summer encephalitis. Techniques and equipment were developed and refined for more efficient cultivation and concentration of the agents. Methods for producing dry weapons formulations for a number of agents also were developed. In addition to weapons to affect humans, a number of weapons to affect crops and livestock were developed.

During this postwar period, which lasted until the signing of the 1972 Biological and Toxin Weapons Convention, the Soviet Union also formulated its doctrine regarding the production and use of biological weapons. In the Soviets' definition, "strategic" weapons were those to be used on the deepest targets, that is, the United States and other distant countries; "operational" weapons were those intended for use on medium-range targets, nearer than the strategic targets but well behind the battlefield; and "tactical" weapons were those to be used at the battlefield. Biological weapons were excluded from use as "tactical" weapons and were divided into "strategic" and "operational" types. "Strategic" biological agents were mostly lethal, such as smallpox, anthrax, and plague; "operational" agents were mostly incapacitating, such as tularemia, glanders, and Venezuelan equine encephalomyelitis. For both types of weapons, use was envisioned on a massive scale to cause extensive disruption of vital civilian and military activity. The Soviets also established so-called mobilization capacities—facilities whose peacetime work was not biological weapons production but that could rapidly begin weapons production if war was imminent.

It is important to note that in the Soviets' view the best biological agents were those for which there was no prevention and no cure. For those agents for which vaccines or treatment existed—such as plague, which can be treated with antibiotics—antibiotic-resistant or immunosuppressive variants were to be developed. This is in sharp contrast to the philosophy of the U.S. program (terminated in 1969 by President Nixon's executive order), which stringently protected the safety of its biological weapons researchers by insisting that a vaccine or treatment be available for any agent studied.

After the Soviet Union became a party to the 1972 Biological and Toxin Weapons Convention, internal debate ensued about the fate of the existing biological weapons program. The end result was that the program was not dismantled but further intensified. During the period 1972 to 1992, the focus of the program was expanded. In addition to continuing previ-

ous types of work (developing improved manufacturing and testing techniques and equipment, developing improved delivery means for existing weapons, and exploring other possible agents as weapons), new emphasis was placed on the following:

- conducting molecular biology and genetic engineering research in order to develop antibiotic-resistant and immunosuppressive strains and to create genetically combined strains of two or more viruses;
- studying peptides with psychogenic or neurogenic effects as possible weapons;
- transforming nonpathogenic microorganisms and commensals into pathogenic microorganisms; and
- testing all of the facilities considered part of the “mobilization capacity” to verify their readiness.

As the Soviet Union weakened during the late 1980s and early 1990s, and as more and more details were revealed to the West regarding the Soviet biological weapons program, the West put increasing pressure on the Soviets. In 1991 a series of trilateral visits of biological facilities was conducted by the United States, Great Britain, and the Soviet Union. The Soviet biological weapons program still existed when these visits took place; the Soviets covered up the evidence as best they could.

After the collapse of the Soviet Union in early 1992, Russian President Boris Yeltsin signed a decree banning all biological weapons-related activity. Considerable downsizing in this area did indeed occur and included destruction of biological weapons stockpiles. However, there still remains doubt that Russia has completely dismantled the old Soviet program. There are some reasons to be concerned that biological weapons research and development are continuing in Russia today.

Russians have steadfastly refused to open their military biological weapons facilities to international inspection. The Russian biological weapons facilities that have received visitors have been those managed by the civilian arm of the Soviet/Russian biological weapons program, Biopreparat. The facilities of the Ministry of Defense, most notably those at Sergiyev Posad (formerly Zagorsk), Kirov, Yekaterinburg, and Strizhi, have never been visited.

Of course, Russia is not the only biological weapons threat the United States faces. A number of other states are known or suspected to possess biological weapons. A more immediate threat, though, is posed by potential terrorist use of biological weapons. The interest of terrorist groups in biological weapons is no surprise. Biological weapons have a number of very attractive features for terrorist uses. Their killing power can approach that of nuclear weapons. They are relatively inexpensive to make. A small-

scale biological weapons attack using a common disease organism, such as tularemia or one of viral encephalitis, can be masked as a natural outbreak. The effects of a biological weapons attack are not apparent for several days, allowing the perpetrator time to vanish. The raw material—disease-producing strains of microorganisms—is fairly easy to obtain. And the techniques and equipment that are used in ordinary biotechnology research and production can be used for biological weapons.

Terrorists interested in biological weapons are on the level of state-sponsored terrorist organizations such as that of Osama bin Laden, on the level of large independent organizations such as Aum Shinrikyo, or on the level of individuals acting alone or in concert with small radical organizations. Although these groups will produce biological weapons with varying levels of sophistication, they all can potentially cause great damage. While the most obvious damages are illness and death, other potential results include panic; direct economic losses due to the costs of medical care, decontamination and other forms of cleanup, crowd control, and collateral agricultural damages such as animal deaths; and indirect economic losses caused by a drop in tourism and/or bans on farm exports from the target area.

Furthermore, there is no doubt that we will see future uses of biological weapons by terrorist groups, as there have been several attempts already. One incident, in 1984, involved members of the Rajneeshee cult contaminating restaurant salad bars in Oregon with salmonella, sickening 751 people. Another involved the Aum Shinrikyo cult. Although best known for its chemical attack in the Japanese subway system in 1995, the cult also attempted to release anthrax from the rooftop of a Tokyo building in 1993. No casualties resulted, but had the cult better understood cultivation of anthrax spores and urban air flow dynamics, the results might have been quite different.

Obviously, as illustrated by the difficulties Aum Shinrikyo experienced in mounting a biological weapons attack, it is not true that anyone who can brew beer can make a batch of biological weapons. Although someone with a strong background in microbiology could certainly produce a crude biological weapon to affect a small number of people and create panic, the production of sophisticated biological weapons requires sophisticated knowledge. For terrorist groups the most likely source of such knowledge would be state-sponsored biological weapons programs, which have the financial and scientific wherewithal to perfect production and deployment techniques. Because the former Soviet Union and Russia had the most sophisticated and powerful biological weapons program on earth, the former Soviet states present a particular proliferation threat. The tremendous knowledge amassed by former Soviet scientists would be extremely useful to both military and terrorist organizations.

When most people think of proliferation, they imagine weapons export. In the case of biological weapons, they picture international smuggling either of ready-made weapons material or at least of cultures of pathogenic microorganisms. However, this area of proliferation is of the least concern. Even without such assistance, a determined organization could obtain virulent strains of microorganisms from their natural reservoirs (such as soil or animals), from culture libraries that provide such organisms for research purposes, or by stealing cultures from legitimate laboratories. To the best of our knowledge, the former Soviet Union and Russia have not exported actual strains of microorganisms.

There are other types of biological weapons proliferation that are of greater concern. The first involves experienced scientists traveling or moving abroad. For example, there have been unconfirmed reports that scientists from the Kirov facility visited North Korea in the early 1990s. In addition, numerous scientists who used to work for the Soviet biological weapons program are now living abroad. Many of these scientists live in the West, but others have gone to Iran and other countries where their expertise can be put to nefarious use in state-run biological weapons programs. A second type of proliferation involves scientists from other countries being brought to a proliferating country for training in biotechnology, microbiology, and genetic engineering techniques. For years Moscow State University provided such training to scientists from dozens of countries, including Cuba, North Korea, eastern bloc nations, Iran, Iraq, Syria, and Libya.

A third form of proliferation involves private companies selling scientific expertise. For instance, a flier from a company advertises recombinant *Francisella tularensis* bacteria with altered virulence genes. Ostensibly, these organisms are being offered for vaccine production; the flier also notes that they can be used as genetic recipients and to create recombinant microorganisms of biologically active agents. The authors of the flier also express willingness to form cooperative ventures to which they will contribute their genetic engineering knowledge. The director of this company used to work for the USSR's biological weapons program.

A fourth type of proliferation occurs when a proliferating country sells equipment that can be used in biological weapons production. Such equipment is generally termed "dual-use," as it can be used for legitimate biotechnology production and for biological weapons production. An example of such proliferation was the planned sale by Russia of large fermenters to Iraq after the Persian Gulf War. Fortunately, the sale was not completed. We have no doubt that these fermenters were destined for use in biological weapons production. First of all, Iraq has used the guise of single-cell protein production as a cover for biological weapons facilities in the past. Second, the particular fermenter size involved in this

proposed sale would not be suitable for efficient single-cell protein production. In fact, the resultant product would be prohibitively expensive. Similarly, in 1990, Biopreparat was negotiating the sale of dual-use equipment to Cuba as well.

The fifth kind of proliferation consists of published scientific literature. Just by reading scientific literature published in Russia in the past few years, a biological weapons developer could learn techniques to genetically engineer vaccinia virus and then transfer the results to smallpox; to create antibiotic-resistant strains of anthrax, plague, and glanders; and to mass produce the Marburg and Machupo viruses. Billions of dollars that the Soviet Union and Russia put into biotechnology research are available to anyone for the cost of a translator.

Given the current economic situation in the states of the former Soviet Union, the incentive to sell equipment and knowledge suitable for biological weapons production without regard to their eventual use is great for both the government and individual scientists and businessmen. The Russian government has long been short of funds, and its biotechnology arena has also been adversely affected. Many of its scientists are unemployed; those who are employed are paid poorly or not at all. Some have been forced to turn to other lines of work, such as street vending. It is important for the international community to ensure that these scientists have legitimate, decent-paying work to do in their fields.

The proliferation issue is particularly complex for biological weapons. In many cases the same equipment and knowledge that can be used to produce biological weapons can also be used to produce legitimate biotechnological products such as vaccines and antibiotics. Thus, we cannot outright forbid the export of most of the relevant knowledge and equipment as we can with nuclear weapons. Even if we did, such regulations would be practically impossible to enforce.

We believe that the United States should strive for transparency in the conduct of dual-use research and in the trade of cultures of pathogenic microorganisms and sophisticated biotechnology equipment. Clear international standards should regulate such trade. Such regulations would entail bans on certain activities, such as the sale of pathogenic microorganisms to individuals not associated with legitimate research institutions—not with the assumption that the ban would be enforceable but to clearly delineate acceptable conduct. The main focus of the regulations, though, would be reporting requirements for the sale or transfer of potentially dangerous cultures, genetic material, or equipment. An international organization would maintain the records of such transfers. While export controls, international treaties and inspection protocols, protective suits, and vaccines all play a role in the defense against biological weapons, none of these can eliminate the threat entirely.

Biological weapons are in essence a medical problem and thus require a medical solution. The ultimate goal of biodefense is to prevent suffering and loss of life. If biological weapons have minimal impact on the well-being of their targets, they are ineffective and thus cease to be a threat. Therefore, we must concentrate on developing appropriate medical defenses. There are three main types of medical defense against biological weapons: pretreatment (administered before exposure), urgent prophylaxis (administered after exposure but before symptoms arise), and chemotherapy (administered after the onset of illness). Pretreatment consists largely of vaccines but also includes certain drugs that can be administered before exposure to prevent disease. Use of pretreatment measures in biodefense will be effective only when all of the following conditions are met:

- The target population is known and limited—that is, military troops within range of an enemy’s arsenal—since it is not realistic to vaccinate or provide drugs to everyone in the country.
- It is known precisely what biological agents are in the enemy’s arsenal or the number of possible agents has been narrowed down to a few, since it is impossible to vaccinate or provide drugs against dozens of agents simultaneously.
- Pretreatment for the agent has already been developed. Note that for many biological agents, among them glanders, melioidosis, Marburg virus, Ebola virus, and Lassa fever, no vaccine exists; for most viral agents no pretreatment exists.
- The biological agents used are not genetically altered strains that are vaccine or drug resistant.

Clearly, pretreatment techniques are of very limited use. Therefore, we cannot rely exclusively or even primarily on pretreatment for medical biodefense. We must also ensure that the means for urgent prophylaxis and treatment of these diseases are available as well. Of the existing drugs that could be useful in urgent prophylaxis and treatment, many are not available in sufficient quantities; some are no longer manufactured. In addition, for many of the agents that can be used as biological weapons, no drug treatment protocols exist. The United States must greatly increase its efforts to develop new treatments and urgent prophylaxis techniques. This should include new approaches, such as preparations that can protect against and treat a wide variety of pathogens.

These efforts, as well as the funds spent on research and development, will pay for themselves many times over. In addition to contributing to preparedness for a biological attack, they will provide a much-needed push in the treatment of infectious diseases that occur under natural conditions. Infectious diseases remain one of the leading causes of death in

the world, resulting in tremendous losses in terms of both money and human lives every year. Furthermore, such medical research would also contribute to the treatment of noninfectious diseases, such as autoimmune disorders and cancer.

The twenty-first century is anticipated to be the century of biotechnology and information technologies. This is a potent mix for future biological weapons development. The rapid advances anticipated in microbiology, molecular biology, and genetic engineering will improve our lives—but they are all dual-use technologies that can also be used in biological weapons development. Our improved knowledge of medicine and the functioning of the human body will enable us to improve human health and quality of life—but can be used to develop more sophisticated biological weapons. The explosive growth of information technology means that anyone with a computer has instantaneous access to tremendous amounts of information—including techniques that can be used in biological weapons development.

We cannot, and should not, halt the progress of science and technology, but we must bear in mind that it is a double-edged sword. To protect ourselves from the threat of biological weapons, we must increase our awareness and understanding of the threat, strengthen current international agreements, increase transparency, and most importantly, develop new medical means to render such weapons useless.

Biological Warfare Scenarios

William Patrick III

INTRODUCTION

This paper will discuss two vulnerability tests, neither of which could be talked about in an open forum until 1999, when the information became public. One of these was a large-scale aerosol test that demonstrated the vulnerability of a seaport, San Francisco. This test took place in 1950. The second test, conducted in 1965, was a simulated attack on an enclosed environment, the subway system of New York City.

LINE SOURCE DISSEMINATION

Today, we tend to talk about biological warfare agents in great detail and ignore the impact of the munitions system, the delivery system, and the meteorological conditions at the target. In addition, a number of important parameters exist that a would-be terrorist must address in order to be successful. Although a discussion of "weaponization 101," as illustrated in Figure 19.1, is beyond the scope of this paper, it is important to discuss the line source dissemination (see Figure 19.2). Line source could be accomplished by a high-performance aircraft, or it could be an individual walking along a line with a 2-gallon spray tank disseminating a liquid perpendicular to the wind, with the energy of the wind taking the aerosol downwind. This is by far the most effective way to deliver a biological warfare agent. Fortunately, line source is very susceptible to meteorological conditions, such as changing winds.

Regarding the nature of the aerosol, it is important to note that there

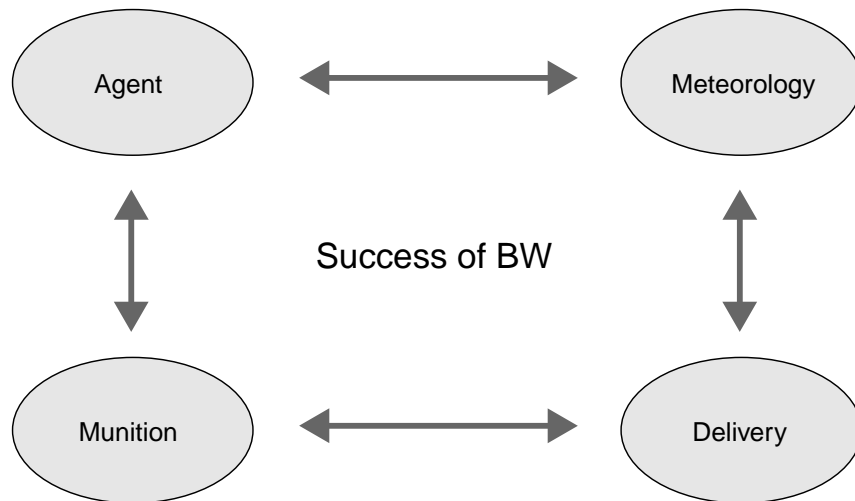


FIGURE 19.1 Four components which must be addressed in an offensive biological warfare program.

Line Source Dissemination

- Delivery vehicle sprays a line perpendicular to the wind
- Target from one to many kilometers downwind
- Wind transports infectious aerosol across target
- Most efficient means of delivering a BW agent, provided meteorological conditions are favorable

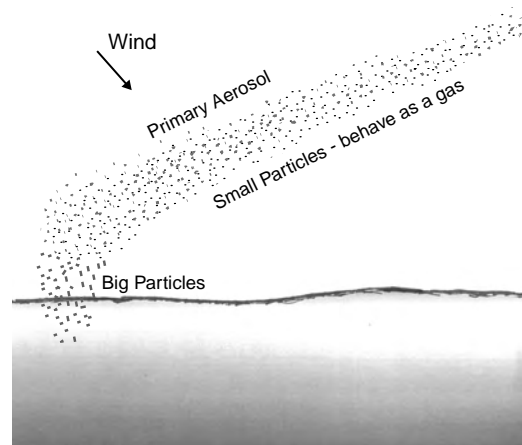


FIGURE 19.2 Line Source Dissemination.

is a period of time immediately following dissemination (whether from an aircraft or any other disseminating device) when the aerosol comes into equilibrium with atmospheric conditions. During this period, referred to as the time of equilibration, the big particles fall out of the aerosol, land on the terrain, and form strong adhesive bonds with the surface (see Figure 19.3).

It is extremely difficult to get these particles to reaerosolize, which is called a secondary aerosol. However, it is the primary aerosol, which is composed of particles within the magic size range of 1 to 5 microns and which behaves as a gas, that remains airborne and causes infections. Once the primary aerosol is formed, these small particles remain airborne. This is one of the major differences between a chemical attack and a biological warfare attack; large quantities of decon are not needed to treat the area over which aerosol passes. Small particles do not fall out. Infections occur because we act as vacuum pumps, pulling in the small particles.

When a helicopter lands in an area that has been potentially contaminated by the fallout of organisms from a primary aerosol (which is very, very low), there will be little or no contamination on the helicopter or the personnel in that area, reflecting the fact that primary aerosols are composed of small particles that remain airborne. Problems arise when the ground is deliberately sprayed directly with either powder or liquid containing microorganisms. As a general rule, the concentration of organisms on the ground must exceed 1×10^7 cells per meter square. This was

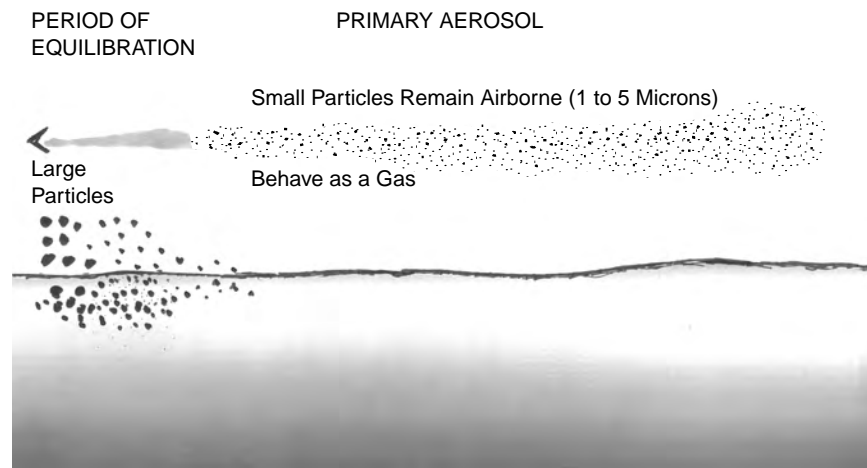


FIGURE 19.3 Physics of Primary Aerosol.

established in early Detrick studies (in the 1950s) and later by a biophysicist at Dugway Proving Ground (35 to 40 years later). Concentrations of 1×10^3 , 10^4 , and 10^5 organisms per square meter do not easily produce secondary aerosols unless high levels of energy are applied. These adhesive bonds are so strong that a high concentration of organism must be reached in order to overcome the bonds between organism and terrain.

The nature of the primary aerosol can be demonstrated effectively by tests conducted in the Pacific and the Arctic. The harmless simulant *Bacillus globigii* (BG) was disseminated in a series of tests demonstrating the vulnerability of naval vessels to small-particle primary aerosols. The aerosol is pulled into the ship by the air system and remains in a high concentration for about 1.5 to 2 hours. Then it departs the ship, leaving very little residue. The primary aerosol, which behaves as a gas, deposits little or no BG spore on the floors and walls of the ship, although the concentration of spores is high in the air. After the aerosol passed through the ship, the floors and doors were swabbed and cultures prepared; however, little contamination was found. In fact, the level of contamination was so low that a small quantity of seawater effectively removed it.

In conducting these simulant tests, the aerosols were sampled with the all-glass impinger (see Figure 19.4). Hundreds of these samplers were used during an open-air test. The impinger contains a fluid—the impinger fluid. Air is pulled in at a specified rate of 10 liters per minute (roughly the breathing rate of a man at rest), due to a calibrated orifice on the outtake. If the material collected in the sampler is determined and the length of time the impinger has operated is known, a relatively accurate fix can be made on the number of spores that would be inhaled by an individual.

SAN FRANCISCO

Using hundreds of these impinger samplers, a vulnerability test was conducted in 1950 on the city of San Francisco using the simulant BG. The purpose of the test was simply to determine if a seaport is vulnerable to biological warfare attack by line source dissemination.

A small naval vessel sprayed a line 2 miles long 2 miles off shore just at sundown using liquid BG (see Figure 19.5). In the first test a strong inversion was present with a gentle wind of about 10 mph. The downtown area of San Francisco was heavily contaminated with samplers, indicating more than 10,000 spores per liter. This concentration would have caused more than 60 percent infections among the population. When an aerosol is released, even under the best of conditions it is difficult to predict where it will go. Thus, the Berkeley area was also contaminated, although at a much lower level. We concluded that this test was highly successful.

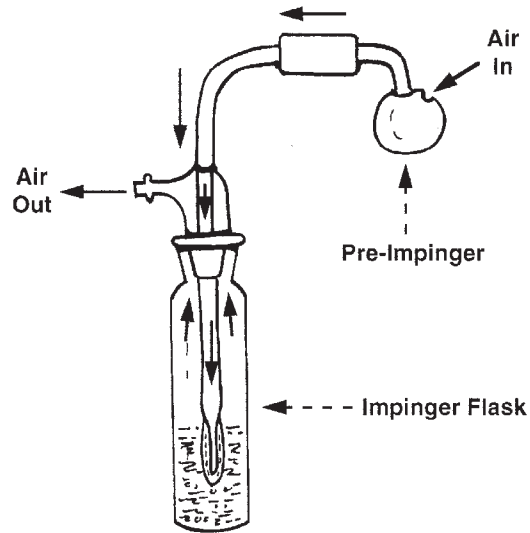


FIGURE 19.4 All glass impinger with pre-impinger.

The next test was conducted in an unstable air mass. Again, BG slurry was disseminated as a line 2 miles long. The same amount of BG was used. A high concentration of spores was found only about two blocks into the city. An unstable air mass failed to achieve the projected casualties, demonstrating that meteorological conditions on an open target are

Simulated Attacks

- San Francisco, 1950
 - *Bacillus subtilis* and *Serratia marcescens*
- Meteorological conditions determined success of "attacks"
 - Optimum conditions would have produced many casualties
 - Poor conditions would have produced few, if any, casualties

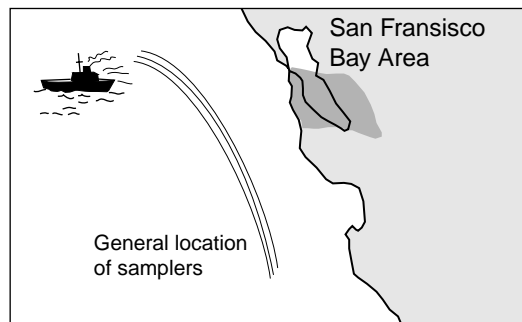


FIGURE 19.5 Simulated attacks.

as important to the success of an attack as the agent, the munition, and the disseminating system.

A vegetative organism, *Serratia marcescens*, was also tested for its ability to contaminate San Francisco. The line of dissemination and general test conditions were similar to those for BG. The dissemination was made under good meteorological conditions, including moderate inversion and a 12 mph wind. The impingers indicated that only about 25 cells were recovered per liter in the first blocks of the city, suggesting that the attack was a failure. Upon subsequent testing we learned that, even though this test had been conducted at sundown, sufficient ultraviolet light was present to kill a vegetative cell. These tests were conducted by a well-supported program that included microbiologists, aerobiologists, meteorologists, and munitions development engineers. The results should be expected to be good if this type of support is available and meteorological conditions are favorable.

DISSEMINATION ISSUES

One of the principles of biological warfare that we learned from our former offensive program is that, although liquid agents are relatively easy to make, they are very difficult to disseminate into a small-particle aerosol. A single-fluid nozzle with gaseous energy is one of the simplest ways to disseminate a biological warfare agent; however, it is not very efficient. Most of the particles are large and fall out of the aerosol quickly. For a single-fluid nozzle to achieve a 5 percent level of efficiency, it would require a minimum of 300 psi. At this level of pressure the container would have to be made of metal, not glass or plastic. The would-be terrorist must not only produce the agent but also requires a model shop in order to construct the agent container and combine it with an appropriate nozzle.

We have discussed big particles that fall out of the aerosol quite quickly. For biological warfare to be successful, a primary aerosol that is composed of 1- to 5-micron particles must be generated. The classic Ft. Detrick experiment compares man to the monkey and guinea pig. The volunteers for this study came from the Seventh Day Adventist Church. It must be emphasized that, at the time this study was conducted, the Soviet Union and Red China were our enemies, and although young people from the Seventh Day Adventist Church wanted to serve their country, they did not want to carry rifles. Therefore, they instead volunteered to be exposed to a series of organisms. The first aerosol tests were conducted with *Coxiella burnetti*, the causative agent of Q fever. Two years later *Francisella tularensis* was used, and still later Staphylococcal enterotoxin B was tested. These diseases are self-limiting and can be effectively treated

with antibiotics. The volunteers recovered and have been followed medically over the years, with no adverse responses noted.

These were very important studies because when the volunteers were exposed, rhesus monkeys and guinea pigs were also exposed. Thus, a relationship was developed between man and the animal models that could then be applied to other diseases to which people could not have been exposed for testing.

The first column of Table 19.1 shows aerosol particle size. The second column demonstrates the number of cells of tularemia required to kill the guinea pig at the 50 percent level, a respiratory LD₅₀. The third column illustrates the number of tularemia cells needed to kill the monkey. The last column shows the number of cells of tularemia required to infect but not kill man (an ID₅₀). An aerosol composed of 1-micron particles of tularemia requires only 2.5 cells to kill the guinea pig, 14 for the monkey, and between 10 and 52 cells to infect man. If the tularemia culture is less than 48 hours, the infecting dose for man is between one and 10 cells. This is the limit of assay precision. However, delivering a culture within 48 hours of its production is not operationally feasible.

When the aerosol is composed of 6.5-micron particles, a larger number of cells are now required to infect by the respiratory route. When the aerosol is composed of 18- to 22-micron particles, the number of tularemia cells becomes extremely large. Man was not exposed to these large particles because of other more important studies such as vaccine efficiency. This experiment clearly demonstrates that the biological warfare agent must be disseminated into a small-particle aerosol.

TABLE 19-1 Dry *Serratia Marcescans* (SM): Relationship of Particle Size, Viable Cells per Particle, and Viable Cells per 1,000 Particles

Aerosol Particle Size	SM per Aerosol Particulate	Viable SM Cells per Aerosol Particulate	Viable SM Cells Frequency per 1,000 Aerosol Particulate
0.8	1.8	0.001	0.5
1.3	4.2	0.01	2.6
3.0	18.0	0.2	15.6
6.5	73.0	2.5	38.0
11.5	195.0	7.7	14.0
16.0	350.0	11.0	60.0

RELIGIOUS CULTS AND BIOTERRORISM

I would like to address the problem of religious cults and bioterrorism, specifically, the Aum Shrinrikyo cult in Japan. Two investigative reporters for the *New York Times*, Miller and Broad, learned from various sources that this well-funded cult had allegedly disseminated liquid anthrax cultures on perhaps as many as nine occasions. All of these attacks failed to produce a single infection, and at the time the attacks were not even detected. Why did the Aum Shrinrikyo fail when the organization had modern laboratories, trained personnel, and sufficient funds? I believe the Aum failed because it did not meet the four essential components presented in Figure 19.1 for a successful biological warfare attack. First, it may not have selected a virulent strain of anthrax. Selection of the virulent strain is the most important in agent weaponization. For example, during the U.S. offensive program, many strains of anthrax were studied before selecting the most appropriate one for weaponization. Next, the munitions and delivery systems may not have been appropriate. Finally, it ignored meteorological conditions. One attack supposedly occurred from an eight-story building, at midday, in downtown Tokyo.

It is important to remember that liquid cultures are difficult to disseminate into small particles, and the disseminating device or munitions requires high levels of energy for success. Table 19.2 illustrates how agent viability interacts with particle size. Dry *Serratia marcescens* or SM is a very small vegetative cell. If the aerosol contains particulates in the 0.8-micron range, there are only 1.8 cells on average in these particles and the viability is 0.001 percent. As particle size increases, the viability of cells in the aerosol particle increases. Thus, big aerosol particulates contain viable cells, yet small particles are most effective in causing a respiratory infection. Therefore, our would-be terrorist has some basic problems that require solutions. (We cannot discuss in an open forum how this and simi-

TABLE 19.2 Classic Experiment: Man-Monkey-Guinea Pig: Influences of Particle Size on Tularemia Infectivity.

Aerosol Particle Diameter (Microns)	Guinea Pig RLD ₅₀	Monkey RLD ₅₀	Man RID ₅₀
1	2.5	14	10 – 52
6.5	4,700	178	14 – 162
11.5	23,000	672	No Data
18	125,000	3,447	No Data
22	230,000	> 8,500	No Data

lar problems are solved.) I suspect that biological warfare may have been attempted in this country and failed, and failure is not usually advertised.

NEW YORK CITY SUBWAY SYSTEM

The next scenario involves an enclosed environment where meteorological conditions are no longer a factor. One of the most important vulnerability studies conducted during our offensive program involved the New York City subway system. A simulant powder containing BG was prepared that possessed very good secondary aerosol properties. Lightbulbs were filled with BG and were dropped from the back of trains onto the subway tracks. Impinger samplers had been distributed throughout the subway system to include both trains and stations.

The passage of the trains over the powder created secondary aerosols that were carried throughout the entire subway system. The BG penetrated all test trains and remained in high concentration for 1 to 1.5 hours. Thereafter, with the dilution factor at work, the concentration dropped markedly, and after 2 hours the impinger samplers were not yielding spores. The risk of infection if a biological warfare agent had been used would have been highest for personnel using the subway near the site of powder drop and within the first hour following dissemination.

Studies have shown that in 1965 the average time people spent on the trains during rush hour (morning and afternoon) was about 8 minutes. Thus, impinger data that determined the number of organisms per liter of air and the number of minutes that people were on a train indicated that about 80 to 90 percent of the train population would have become infected. (If treatment is not started early in the disease process when the first subtle symptoms appear, anthrax is fatal.)

CONCLUSION

At this time, domestic terrorists do not have the capability to develop a biological warfare weapon that would result in serious casualties. However, there is concern that a state-supported group with trained personnel and adequate laboratories and funds could develop an agent powder with the appropriate biological and physical properties and that a few hundred grams of this powder, which could enter the United States via those with diplomatic immunity, if used in an enclosed environment, would produce thousands of casualties. The questions then become: How does the United States determine the perpetrator? and What is the response?